Attachment M Materials for Technical Transfer for Wind

Guideline for Wind Power

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Rural Electrification Authority

Ministry of Energy and Petroleum

JICA

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List of Terms and Abbreviations

Abbreviation	Description
AC	Alternating Current
a.g.l	Above Ground Level
a.s.l	Above Sea Level
BCS	Battery Charging Station
BOS	Balance of System
CEO	Chief Executive Officer
Cp	Power Coefficient
DC	Direct Current
EA	Environmental Audit
EIA	Environmental Impact Assessment
EIA-TAC	Environmental Impact Assessment Technical Advisory Committee
EMCA	Environmental Management and Coordination Act
ERC	Energy Regulatory Commission
GEF	Global Environment Facility
GoK	Government of Kenya
HH	Household
JET	JICA Expert Team
JICA	Japan International Cooperation Agency
JKUAT	Jomo Kenyatta University of Agriculture and Technology
NASA	National Aeronautics and Space Administration, USA
NEDO	New Energy and Industrial Technology Development Organization
NEMA	National Environment Management Authority
MoE&P	Ministry of Energy and Petroleum
MHP	Micro Hydropower
PV	Photovoltaic
REA	Rural Electrification Authority
SEA	Strategic Environmental Assessment
SG	Synchronized Generator
SVO	Straight Vegetable Oil
SWERA	Solar and Wind Energy Resource Assessment

List of Electrical Terminology

Unit	Description
A (Ampere)	Unit of current
V (Volt)	Unit of voltage
kV (kilovolt)	1,000 volts
W (Watt)	Unit of active power
kW (kilowatt)	1,000 watts
MW (Megawatt)	1,000kW
VA(Volt-Ampere)	Unit of energy
kVA(kilovolt-ampare)	1000 VA
Wh (Watt-hour)	Unit of energy
kWh (kilowatt-hour)	1,000Wh
MWh (Megawatt-hour)	1,000kWh
Wp (Watt-peak)	Unit of PV output
kWp (kilowatt-peak)	1,000Wp
MWp (Megawatt-peak)	1,000kWp
Pa (Pascal)	Unit of pressure
hPa (hect-Pascal)	1000Pa
K (Kelvin)	Unit of temperature K(K)=T(^{o}C) + 273.15^{o}C

EXCECUTIVE SUMMARY

1. Background

"Project for Establishment of Rural Electrification Model using Renewable Energy in the Republic of Kenya" is a project which Japan International Cooperation Agency (JICA) has collaborated with counterpart agencies of Ministry of Energy and Petroleum (MoE&P) and Rural Electrification Authority (REA). The project started in March 2012 with the cooperation period of three years.

2. Objective

The project outline extracted from Project Design Matrix is as shown below.

Overall Goal	Rural electrification models using renewable energy are disseminated in the country to improve the quality of Kenyan's life.
Project Purpose	Rural electrification models using renewable energy are established
Outputs	(1) A practical model for PV electrification of health service institutions in non-electrified areas is developed through pilot projects. (2) A practical model for PV electrification of schools in non-electrified areas is developed through pilot projects. (3) The Capacity of REA / MOE&P to undertake project using MHP, Biogas and Wind technologies is enhanced. (4) Necessary policy and institutional frameworks for spreading the models for rural electrification using renewable energy are recommended.

The objective of technical cooperation on wind technology is enhancement of the capacity of REA and MoE&P to undertake wind projects in Kenya. This guideline has been developed under the cooperation of JICA, REA and MoE&P, for REA and MoE&P staff conducting projects on wind energy development in Kenya.

3. Structure of the guideline

Analysis of wind potential is the most important topic in the guideline. Wind analysis is an essential for project implementation organizations in the planning of wind power development.

The followings show the chapter of guidelines.

- CHAPTER 1 GENERAL
- CHAPTER 2 ANALYSIS OF WIND POTENTIAL
- CHAPTER 3 MICRO/SMALL WIND SYSTEM
- CHAPTER 4 WIND-DIESEL HYBRID SYSTEM
- CHAPTER 5 OPERATION & MAINTENANCE
- CHAPTER 6 ECONOMIC CONSIDERATIONS
- CHAPTER 7 ENVIRONMENTAL AND SOCIAL CONSIDERATIONS
- CHAPTER 8 PROCUREMENT

In Chapter 1, General information of wind power development is explained. In Chapter 2, calculation procedures for analyzing wind power using spreadsheets such as EXCEL are explained. Reader can understand meaning of the calculation and analysis practically. In addition, it is useful for who interested in the estimation of the power output from wind. Chapter 3 explains Micro and Small wind turbines which usually applied for isolated wind system with battery storage. In addition, wind solar PV hybrid system is also explained in this chapter. Chapter 4 explains Wind and Diesel hybrid system. At diesel power station, wind turbine can be intergraded to existing mini-grid if steady and strong wind is available. In Chapter 5, basics of operation and maintenance of wind turbine are written. Chapter 6 describes economical analysis on wind and diesel hybrid system. In addition isolated solar

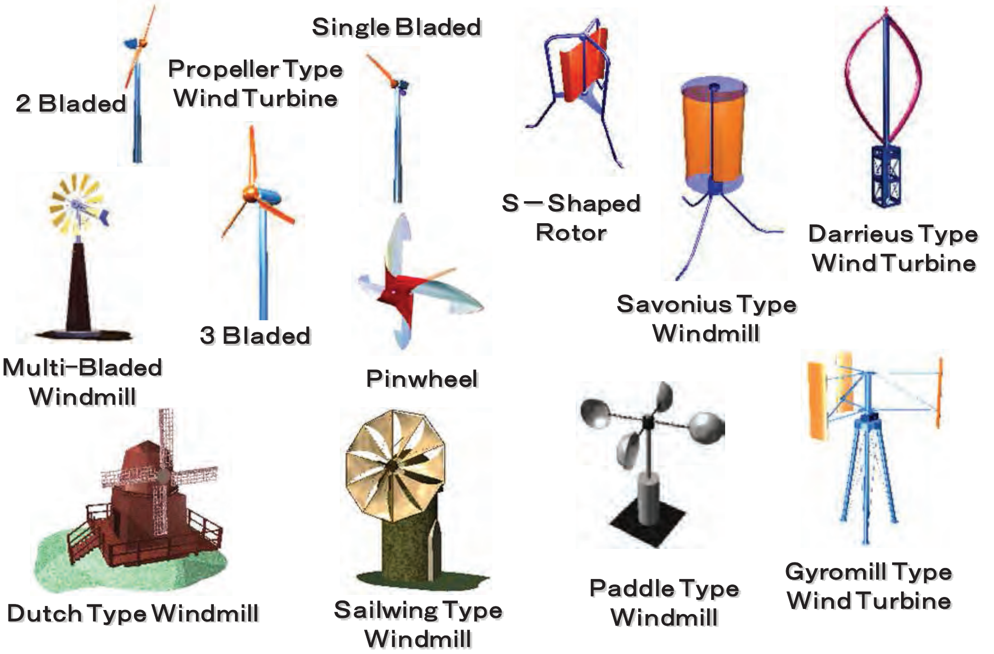
PV and small wind are compared from economical aspect. Chapter 7 explains procedures to gain environmental assessment or report. And in Chapter 8, procurement procedure is explained.

CHAPTER 1. GENERAL

1.1 Applications of Wind Technology

1.1.1 Types of Windmills

There are various types of windmills used for different purposes. The following figure shows various types of windmills and wind turbines.



Source: Ashikaga Institute of Technology

Figure 1.1.1 Types of Windmills / Wind Turbines

1.1.2 Horizontal - Axis Windmills / Wind Turbines

(1) Dutch Type Windmill

A windmill is a machine that converts energy from wind into rotational energy by means of blades or sails. By the early 19th century, approximately 10,000 windmills were used in the Netherlands. Currently, only an estimated 1,000 windmills still exist.. These windmills are usd for purposes including pumping water, keeping the lowlands dry, sawing wood and grinding grain. Most Dutch Type Windmills have four blades.

(2) Multi-Bladed Windmill

In the middle of the 19th century, Multi - Bladed Windmills were used for irrigation and live stock farming in U.S.A. This type of windmill is now used all over the world, and there are also some manufacturing companies in Kenya.

(3) Propeller Type Wind Turbine

The windmill used for power generation is called a wind turbine or a wind-power generator. The Propeller Type is the most popular wind turbine. It is called a Horizontal - Axis Windmill because the axis of the rotor is in horizontal plane. The cross section of the blade is the same as the propeller of an airplane. Hydrodynamically, the rotational speed increases as much as the number of blades decreases. In general, a 3-bladed rotor which is superior in balance is used.

(4) Sailwing Type Windmill

There are still around 6,000 Sailwing Type Windmills in Crete in Greece. This type of windmill has sails which are triangular in shape.

1.1.3 Typical Vertical – Axis Windmills / Wind Turbines

(1) Paddle Type Windmill

The Paddle Type Windmill is populary used as an anemometer.

(2) S-Shaped Rotor

S-Shaped Rotor is a windmill of the oldest configuration. The windmill is rotated by resistance (drag force) of the wind.

(3) Darrieus Type Wind Turbine

Darrieus Type Wind Turbine consists of a number of curved aerofoil blades mounted on a vertical rotating shaft or framework.

(4) Savonius Type Windmill

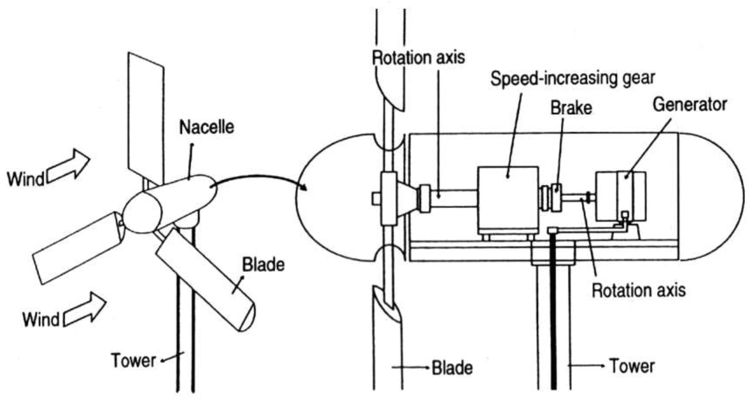
Savonius Type Windmill is a drag-type device, consisting of two or three scoops.

1.1.4 Components of a Wind Turbine

The following figure shows basic design of a wind turbine. A wind turbine consists mainly of blades, generator, gears, nacelle and tower.

Blades
Blades are one of the most critical and visible components of a wind turbine. For Propeller Type Wind Turbines, rotors using two or three blades are the most common, though there are also one-blade wind turbines. Wind turbines require only one blade to capture energy from the wind. However, a one-blade wind turbine requires higher rotational speed to yield the same energy output as a two-blade turbine.

Currently, modern wind turbines use three rather than two blades because they give greater dynamic stability. A rotor with an odd number of blades and at least three blades will have stable operation.



Source: Ashikaga Institute of Technology

Figure 1.1.2 Components of a Wind Turbine

<u>Generator</u>

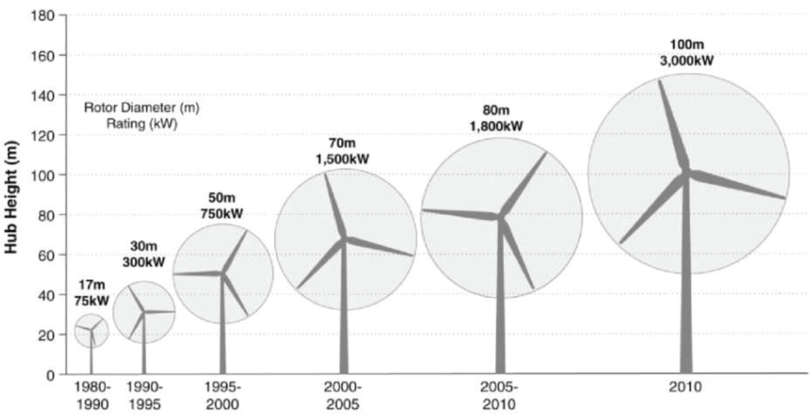
The generator converts the mechanical power of the spinning wind turbine rotor to electrical power. Power generation by wind turbines is unusual technology compared to other generating systems connected to power grid because wind turbines have to produce power from wind, which supplies very fluctuating input.

Generators are divided into two types; synchronous and induction.. A synchronous generator operates at exactly the same frequency as the connected grid. Synchronous generators are also called alternators. An induction generator operates at a slightly higher frequency than the connected grid. Induction generators are also called asynchronous generators.

<u>Tower</u>

Towers are integral to the performance of a wind turbine. Wind speeds increase at higher altitudes due to surface aerodynamic drag and the viscosity of the air. The wind speed variation with altitude, called wind shear, becomes larger nearer the ground surface.

The figure below shows that in 1980's, the largest commercial wind turbines were producing around 75 kW of electrical power, with a rotor diameter of approximately 17m and a tower height of a little over 20m. However, 10 years ago, the largest turbines were producing around 2 MW, with a larger rotor diameter of approximately 80m and a tower height of 80 m.

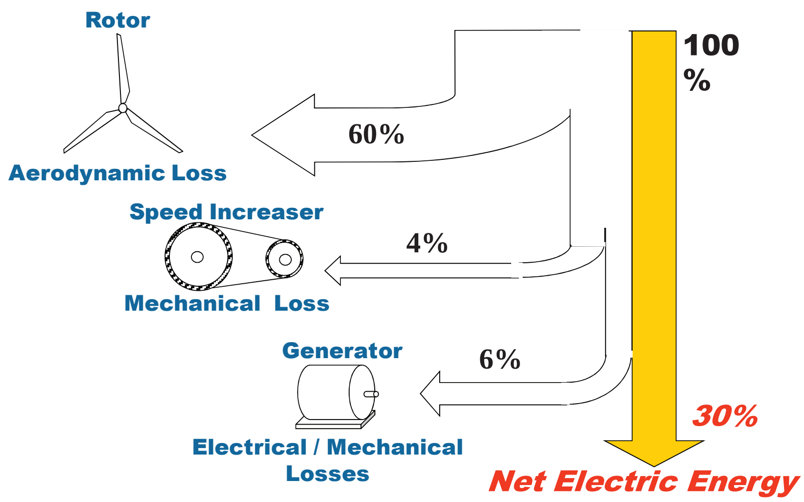


Source: Wind Power

Figure 1.1.3 Rotor Diameter and Height of Wind Turbine

1.1.5 Energy from Wind Turbine

There are numerous energy losses in the process of producing electric energy from wind power using wind power generators. At rotor, there is aerodynamic loss of around 60% of wind power input. Further, there are mechanical losses of around 4% at speed increasers such as gears, and electrical and mechanical losses of around 6% at generator. In total, about 70% of wind power input is lost through wind power generator. Therefore, net electric energy becomes around 30% of wind power input.



Source: Ashikaga Institute of Technology

Figure 1.1.4 Energy from Wind Turbine

1.2 Wind Power for Rural Electrification in Kenya

The wind turbines installed in Kenya can be broadly categorized by capacity, system configuration and main objectives for use, as shown in Table 1.2.1.

Table 1.2.1 Capacity, System Configuration and Main Objectives for Use of Wind Power

System configuration	Capacity	Main objectives for use
Micro and small class wind turbines	Less than 1kW	Isolated power supply systems Individual households and public facilities such as schools and clinics. Installed for uses such as water pumping and communication in non-electrified communities
Wind hybrid systems	1kW and over Less than 20kW	Isolated power supply systems Public facilities such as schools and clinics Installed as mini grid community systems
Middle and large class wind turbines	20kW and over (middle) 1000 kW and over (large)	Grid-connected systems Installed as wind farms

Prepared by JET

(1) Micro and Small Class Wind Turbines

Micro and small wind turbines are used to supply power to individual households, public facilities such as school and health clinics, base telecommunication stations and so on. Most of these installations are operated as autonomous power supply systems with battery banks.

REA has installed two small wind turbines, each with 3kW capacity at the following sites:

- Patterson Memorial Secondary School – Kajiado District
- North Horr Boys Secondary School – Marsabit District

UNIDO has also installed a small wind turbine in a hybrid system at the following site:

- Olosho Oibor Community Centre – Kajiado District

  PV : 2 kW

  Wind : 3 kW

  SVO : 9 kW

There are several private companies operating businesses in small wind turbines as well as several NGOs implementing projects using small wind turbines. Most of the private companies are operational in both solar PV and small wind turbine technologies.

Winafrique Technologies Ltd. is one such private company which as of 2011 had installed about 229kW of wind and solar PV systems. The following shows the distribution of system configurations installed by Winafrique Technologies Ltd.

- Wind, solar, battery, diesel hybrid: 104 systems
- Wind, battery, diesel hybrid: 3 systems
- Wind electric water pumping: 1 system

The most disseminated systems are used to power isolated base telecommunication stations.

In addition, there are companies manufacturing micro and small wind turbines which are used to power individual households, schools, clinics and public wells. Existing wind companies are listed in Chapter 3.2.

Establishment of a small wind association is currently under consideration by stakeholders such as universities, companies and NGOs.

(2) Wind Hybrid Systems

Hybrid power supply systems comprised of wind turbines and diesel generators are operated in some non-electrified communities. Some have been installed in public facilities such as schools and health clinics. There are also future plans to further disseminate such wind hybrid power supply systems. Technical cooperation and knowledge transfer on such small wind hybrid systems will be conducted.

Existing wind hybrid systems are shown in Table 1.2.2.

Table 1.2.2 Wind Hybrid Systems

Location	Installed capacity
Modogashe District, (Habaswein DPS, 52 km South West of Habaswein)	Diesel: 400 kW Solar PV: 50 kW Wind: 60 kW (20 kW x 3)
Marsabit	Diesel: 2000 kVA Wind: 490 kW (245 kW x 2)

Prepared by JET

(3) Middle and Large Class Wind Turbines

There are several grid connected wind systems which consist of middle class wind turbines in a wind farm configuration. A wind farm is located at Ngong' Hills near Nairobi. Areas with the highest wind potential can be found in Northern Kenya.

1) Ngong’ Hills

Ngong Power Station wind farm began with two wind turbines commissioned in 1993 as a donation from the Belgian Government. the two turbines have since been retired. The second phase of the Ngong wind farm was commissioned inAugust 2009 and has a capacity of 5.1 MW of power. The grid-connected facility is on the northern part of the Ngong Hills, near

Kenya's capital, Nairobi. Work on the wind farm, which consists of six (6) Vestas V52-850kW Wind Turbines, began in May 2008.
The northern part of the Ngong hills was chosen as the project site because KenGen had for a period of 14 years observed a favorable wind regime as measured by two experimental wind turbines which were installed on the hill in the early 1990s. This data was further supplemented by measurements taken from the site between August 2006 and August 2007. A feasibility analysis conducted using this data confirmed that the Ngong site was capable of generating up to up to 14.9GWh of energy per annum on average from a 5.1MW wind farm. KenGen intends to increase its installed capacity for wind energy at the northern part of the Ngong Hills from the current 5.1MW to 25.5MW.

(Source: KenGen HP (http://www.kengen.co.ke/))

Taken by JET

Photo 1.2.1 Ngong' Hill Wind Farm

2) Turkana

The Lake Turkana Wind Power Project (LTWP) aims to provide 300MW of reliable, low cost wind power to the Kenya national grid, equivalent to approximately 20% of the current installed electricity generating capacity. The Project is of significant strategic benefit to Kenya, and at Ksh76 billion (€623 million) will be the largest single private investment in Kenya's history. The wind farm site, covering 40,000 acres (162km2), is located in Loyangalani District, Marsabit West County approximately 50km north of South HorrTownship.

・50 to 90MW of capacity to be commissioned by late 2015
・The wind farm will be fully operational at 300 MW by2016

(Source:LTWP (http://www.ltwp.co.ke/))

CHAPTER 2. ANALYSIS OF WIND POTENTIAL

2.1 Measurement of Wind Power

Wind speed and direction vary in the short and the long term. Gusts occur within seconds. Average wind speeds may change with the time of the day or the season of the year. Some years may be exceptionally windy, while others may be calmer than average. Wind speed is affected by the terrain and by height above ground. The power of the wind turbine is approximately proportional to the cube of the wind speed, so that doubling the wind speed increases the power output by a factor of eight.

Wind measurement and analysis of obtained data are so important in the implementation of wind projects. Overestimating wind speed will result in the available wind energy being less than expected, which may be disastrous for the economics of the project. Underestimates are less dangerous in the economic sense but may mean that a wind turbine with a larger generator should have been installed, thereby maximizing the overall savings.

The power in the wind is proportional to the cube of the wind speed. It is therefore essential to have detailed knowledge of wind and its characteristics. As is well known, the highest wind speeds are generally found on hill tops, exposed coasts and out at sea. Various parameters of the wind need to be known, including mean wind speed, directional data, daily seasonal and annual variations, and variation with height. These parameters are highly site specific and can only be determined with sufficient accuracy by measurements at the particular site over a sufficiently long period. They are used to assess the performance and economics of wind projects.

The following section explains the complex processes which produce the information on wind parameters in a particular location. These processes consider in more detail, the practical quantitative description of wind characteristics.

2.1.1 Measurement Plan

The main objective of wind monitoring is to identify potential wind development areas that also possess other desirable qualities of a wind energy development site. In Kenya, a nationwide wind potential map already exists and it is therefore easy to identify areas with good wind potential, for wind monitoring. There are three steps to be undertaken in wind monitoring:

- Identification of potential wind development areas;
- Inspection and ranking of candidate sites; and
- Selection of actual tower location(s) within the candidate sites.

For the wind development plan, it is necessary to prepare measurement methodologies for wind monitoring. The following features should be specified in the preparation.

- Measurement parameters
- Equipment type, quality and cost
- Number and location of monitoring stations
- Sensor measurement heights
- Minimum measurement accuracy, duration and data recovery
- Data sampling and recording intervals
- Data storage format
- Data handling and processing procedures
- Quality control measures
- Format of data reports

2.2 Examination of Wind Power Potential

Wind analysis will be conducted to evaluate the wind characteristics based on the results of wind monitoring at candidate sites. On the basis of the results, power outputs from wind turbines will be estimated and the installed capacity of the project decided consequently.

2.2.1 Monitoring Duration

The minimum wind monitoring duration should be one year, but two or more years will produce more reliable results. One year is usually sufficient to determine the diurnal and seasonal variability of the wind. Inter-annual variability of the wind can also be estimated by comparing the data monitored at long-term reference stations such as airports and meteorological stations. The data recovery for all measured parameters should be at least 90% over the program's duration, with any data gaps kept to a minimum. Any data gaps should therefore not exceed one week.

2.2.2 Wind Monitoring

In general, wind monitoring stations for wind power development should only be installed for a limited period. Permission for the establishment of wind monitoring stations should be acquired from the land owner(s). The following table shows the basic and optimum parameters which should be examined in the evaluation.

Table 2.2.1 Basic and Optimum Parameters

Measured Parameters	Recorded Values
Wind Speed (m/s)	Average Standard Deviation Maximum/Minimum
Wind Direction (degrees)	Average Standard Deviation Maximum Gust Direction
Temperature (°C)	Average Maximum/Minimum
Barometric Pressure (hPa)	Average Maximum/Minimum
Solar Irradiation (W/m^2)	Average Maximum/Minimum

Source: NREL Wind Resource Assessment Handbook

(1) Wind Speed

Wind speed data is the most important indicator of a site's wind energy resource. Multiple measurement heights are encouraged for determination of a site's wind shear characteristics, conducting turbine performance simulations at several turbine hub heights, and for backup.

(2) Wind Power

The amount of energy in the wind is a function of its speed and mass. At higher wind speeds, more energy is available. Wind energy is the rate at which energy is available, or the rate at which energy passes through an area per unit time. The following formula shows the power that can be generated from wind.

$$P = \frac{1}{2}\rho A V^3$$

P: wind power (W)

ρ : Air density (kg/m^3)

A: Swept area (m^2)

V: Wind velocity (m/s)

The following table is presented in the form of spreadsheet. The formula for calculating the values are given in the cells. Also, input data are written in the cells. The following spreadsheet is for calculating wind power.

Table 2.2.2 Spreadsheet for Calculating Wind Power

	A	B	C	D
1	P: wind power	P =	=0.5*C2*C3*C4^3	(W)
2	ρ :Air density	ρ =	1.225	(kg/m^3)
3	A: Swept area	A =	=(C5/2)^2*PI()	(m^2)
4	V: Wind velocity	V =	2	(m/s)
5	D: Roter diameter	D=	10	m

Prepared by JET

Air Density: Air density can be calculated using the gas law as a function of change in temperature and pressure as shown in the following equation. For example, air density at standard temperature of 15 ^{0}C at sea level is 1.225 kg/m^3

$$\rho = \frac{P}{RT}$$

ρ : Air Density (kg/m^3)

P: Air pressure (N/m^2)

R: Gas Content (287.04 J/kgK)

T: Temperature in Kelvin

The following spreadsheet is for calculating air density.

Table 2.2.3 Spreadsheet for Calculating Air Density

	A	B	C
1	ρ: Air Density=	=B2/B4/B5	kg/m^3
2	P:Air pressure (N/m^2)	=B3*100	N/m^2
3		1022	hPa
4	R:Gas Content (287.04 J/kgK)	287.04	J/kgK
5	T:Temperature in Kelvin	=B6+273.15	K
6		16	℃

Prepared by JET

Air pressure at certain elevation is calculated from elevation above sea level, ambient temperature and air pressure at sea level.

$$P = P_0\left(1 - \frac{0.0065h}{T + 0.0065h + 273.15}\right)^{5.257}$$

P: Air pressure (hPa)
P_0: Air pressure at sea level (1.225 hPa)
T: Temperature (^{0}C)
h: Elevation above sea level (m)

The following table shows relation between elevation above sea level and air density. Air density becomes smaller with increase of the elevation.

Table 2.2.4 Elevation vs. Air Density

Elevation above sea level (m)	Air pressure (hPa)	Air Density at 15℃ (kg/m^3)
0	1013.25	1.225
500	955.23	1.155
1000	901.13	1.089
1500	850.63	1.028
2000	803.47	0.971

Prepared by JET

The following spreadsheet shows the formula of the table above.

Table 2.2.5 Spreadsheet for Calculating for Air Pressure and Density

	A	B	C
1	Elevation above sea level (m)	Air pressure (hPa)	Air Density at 15℃ (kg/m^3)
2	0	1013.25	1.225
3	500	=$B$2*(1-(0.0065*A3)/(15+0.0065*A3+273.15))^5.257	=B3*100/$C$7/(273.15+15)
4	1000	=$B$2*(1-(0.0065*A4)/(15+0.0065*A4+273.15))^5.257	=B4*100/$C$7/(273.15+15)
5	1500	=$B$2*(1-(0.0065*A5)/(15+0.0065*A5+273.15))^5.257	=B5*100/$C$7/(273.15+15)
6	2000	=$B$2*(1-(0.0065*A6)/(15+0.0065*A6+273.15))^5.257	=B6*100/$C$7/(273.15+15)
7		Gas Content (J/kgK):	287.04

Prepared by JET

(3) Wind Direction

Wind direction frequency information is important in identifying preferred terrain shapes and orientations and in optimizing the layout of wind turbines in a wind farm. Prevailing wind directions will have to be defined.

(4) Temperature

In most locations, the average ambient temperature near ground level (at 2 to 3 m) falls within 1°C of the average temperature at hub height. The average temperature will also be used to calculate air density. Wind power density will be used to calculate the wind power output from the wind turbine.

(5) Vertical Wind Speed

Wind speed and power vary with the height above ground level. However, it is difficult to measure wind speed at the exact hub height, especially at 80 meters. It will therefore be necessary to monitor wind speed in at least two different lower heights to estimate the wind speed at higher heights.

The following equation illustrates how to use the power law method; where V_0 is the wind speed at the original height, V is the wind speed at the new height, H_0 is the original height, H is the new height and α is the wind shear exponent.

$$V = \left(\frac{H}{H_0}\right)^{\alpha} V_0$$

V_0: Wind speed at original height

V: Wind speed at new height

H_o: Original height

H: New height

α: Wind shear exponent

The following spreadsheet is for calculating wind speed at new height.

Table 2.2.6 Spreadsheet for Calculating Wind Speed at New Height

	A	B	C	D
1	V:	Wind speed at new height	=C2*(C4/C3)^C5	m/s
2	V_0:	Wind speed at original height	5	m/s
3	H_o:	Original height	10	m
4	H:	New height	80	m
5	α:	Wind shear exponent	0.16	

Prepared by JET

Table 2.2.7 Wind Shear Exponent

Terrain	Wind Shear Exponent α
Coastal areas	0.11
Cut grass	0.14
Short-grass prairies	0.16
Crops, tall-grass prairies	0.19
Scattered trees and hedges	0.24
Trees, hedges, a few	

Terrain	Wind Shear Exponent α
buildings	0.29
Suburbs	0.31
Woodlands	0.43

Source: Wind Power

If wind speeds are monitored at different heights, it is possible to calculate the wind shear exponent using the following equation:

$$\alpha = \frac{\ln\left(\frac{V}{V_0}\right)}{\ln\left(\frac{H}{H_0}\right)}$$

The following spreadsheet is for calculating wind shear exponent.

Table 2.2.8 Spreadsheet for Calculating Wind Shear Exponent

	A	B	C	D
1	V	Wind speed at higher height	=C2*(C4/C3)^C5	m/s
2	V_0	Wind speed at lower height	5	m/s
3	H_o	Lower height	20	m
4	H	Higher height	40	m
5	α	Wind shear exponent	0.16	

Prepared by JET

6. Barometric Pressure

Barometric pressure is used in combination with air temperature in order to determine air density. However, it is difficult to measure barometric pressure accurately in windy environments because of the dynamic pressures induced when wind flows across an instrument's enclosure. An indoor or office environment is the preferred location for a pressure sensor. Most resource assessment programs therefore use data collected by SNET stations, rather than measure barometric pressure. The data from SNET stations is then adjusted for elevation.

2.2.3 Monitoring Height

Typical wind monitoring heights for both wind speed and direction are 40 m, 25 m, and 10 m. However, hub heights could be higher and also increase as the wind turbine capacity increases. In general, the typical hub height of a 1 MW wind turbine is about 60 meters, while that of a 2 MW wind turbine is around 70 to 80 meters. It is therefore necessary to monitor wind speeds at heights which are as close to the hub height as possible.

In addition, ambient temperature, barometric pressure and solar radiation are monitored 2 to 3 meters above ground level.

2.2.4 Placement of Wind Monitoring Towers

Two important guidelines should be followed when choosing the location for a monitoring tower:

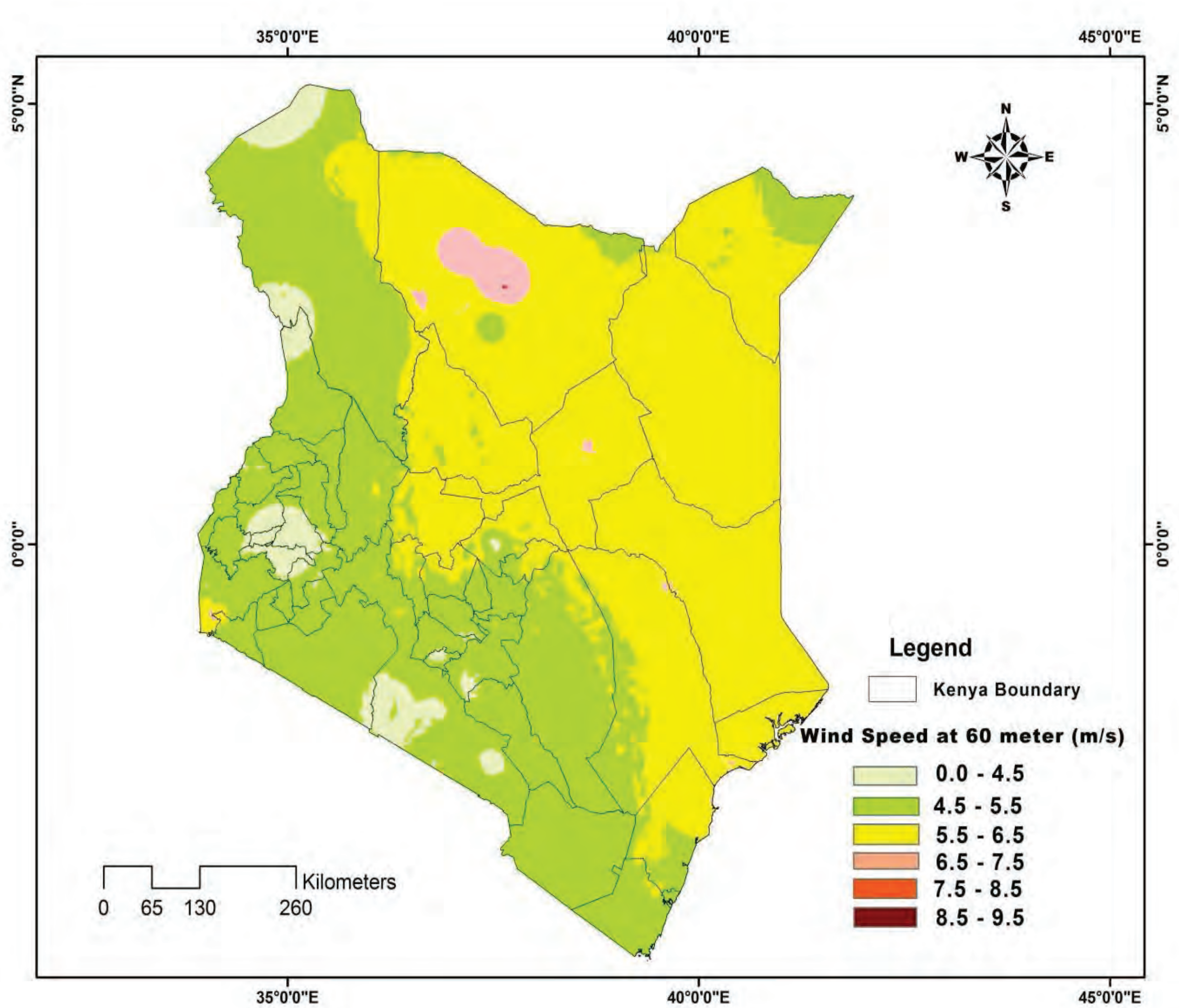
- Place the tower as far away as possible from local obstructions to the wind.
- Select a location that is representative of the majority of the site.

Siting a tower near obstructions such as trees or buildings can adversely affect the analysis of the site's wind characteristics. The presence of these features can alter the perceived magnitude of the site's overall wind resource, wind shear and turbulence levels. As a rule, if sensors are near an obstruction, they should be located at a horizontal distance of more than 10 times the height of the obstruction in the prevailing wind direction.

2.3 Wind Potential in Kenya

Under Energy Sector Recovery Project (ESRP) Credit No IDA 45720, Contract No MOE/RFP/04/2012 – 20131, Ministry of Energy (MoE), Government of Kenya carried out wind energy data analysis and development programme. The ESRP is one of the key projects initiated by the Government of Kenya Vision 2030 which aims at addressing some of the key challenges faced by the power sub sector.

The following figure shows the wind resource potential in Kenya.



Source: FINAL REPORT FOR WIND ENERGY DATA ANALYSIS AND DEVELOPMENT PROGRAMME

Figure 2.3.1 Wind Potential Map (60m a.g.l)

2.4 Analysis of Wind Potential

2.4.1 Wind Evaluation

(1) Monitoring Data

Table 2.4.1 shows the list of wind power data to be evaluated based on the results of wind monitoring. For each evaluation item, the purpose and procedures for wind monitoring are stated.

Table 2.4.1 List of Wind Power Data for Evaluation

	Items	Term	Purpose	Procedure
Wind Condition	Average Wind Speed (m/s)	Annual Monthly	Evaluation of wind speed	Average Wind Speed ＝Sum of all hourly averaged value in of monitoring term / No. of data
	Wind Speed Frequency Distribution(%)	Annual	Evaluate characteristic of wind speed by wind speed frequency distribution	A wind speed class is established every 1m/s and calculates the relative frequency of each class
	Wind Direction Frequency Distribution (%)	Annual	Clarify prevailing wind direction	All wind direction is divided into 16 direction and accumulate in mean wind direction
	Directional Wind Speed (m/s)	Annual	Clarify prevailing wind direction to consider siting of wind turbines	An arithmetic average based on hour mean wind speed is calculated every direction
	Wind Speed Directional Frequency Distribution (%)	Annual	Clarify prevailing wind direction to consider siting of wind turbines	Relative frequency of each wind speed class (1m/s step) is calculated every azimuth
	Diurnal Wind Speed (m/s)	Diurnal Annual	Time variability of wind speed is evaluated for operational plan of the wind turbines	The average hourly wind speed of each month is calculated and clarifies the transaction by chart
	Turbulence intensity	Annual	Fluctuation properties of the wind speed and the direction with large wind speed fluctuation is clarified	It is calculated for the wind speed for all azimuth direction and each direction. Intensity of turbulence =standard deviation of wind speed / mean wind speed
	Vertical Wind Speed	Annual	Power index to predict wind speed at certain height is calculated and clarified vertical distribution of the wind speed	Each monitoring height and the wind speed are substituted for following formula and calculate it by a least squares $V/V1 = (Z/Z1)^{1/n}$
Wind Energy	Utilization Factor	Annual	Operational conditions of the wind turbine are clarified	It accumulates from the high wind speed side in wind speed relative frequency and calculates cumulative relative frequency. Utilization Factor = Cumulative relative frequency higher than cut-in wind speed - Cumulative relative frequency higher than cut-out wind speed
	Power Availability (Annual Power Output) ($kWh/m^2/year$)	Annual Monthly	Amount of power output that can be acquired from wind power generation is evaluated	It is accumulated in annual power output at every wind speed based on power curve of wind turbine and wind speed relative frequency.
	Capacity Factor	Annual Monthly	Possibility of the introduction of the wind power generation is evaluated	Capacity factor = power output / (reted power output x operational hours)

Source: Guidebook for Wind Power Introduction / NEDO

(2) Evaluation

Suitable wind characteristics for wind power development are high average wind speed, steady wind direction and small intensity of turbulence.

a. Average Wind Speed

Sites where the annual average wind speed **exceeds 6 m/s at 30 m** above ground level are acceptable for wind power development.

$$\text{Average Wind Speed (m/s)} = \frac{Sum\ of\ hourly\ average\ value\ in\ monitoring\ period\ (m/s)}{Number\ of\ monitored\ data}$$

In the following tables, the one on the left shows a sample of datasheet on wind speed at 20 meters and 40 meters above ground level which were recorded every 10 minutes. The average wind speeds are calculated using functions of spreadsheet such as "AVERAGE (c3:c5000). The table on the right summarizes emergence frequency of wind speeds.

Table 2.4.2 Datasheet and the Result of Wind Speed Evaluation

	A	B	C	D	E	F	G	H	I	J	K
1	date	time	Wind Speed Avg. (m/s) 20m (a.g.l)	Wind Speed Max. (m/s) 20m (a.g.l)	Wind Speed Min. (m/s) 20m (a.g.l)	Std. deviation 20m (a.g.l) (sig)		Wind Class	Range of Wind Speed (m/s)	No. of Data	Frequency (%)
2			**5.70**	**7.56**	**3.97**	**0.70**		0	0<V<0.5	0	0.0%
3	01.09.2010	0:00:00	6.5	8.7	4.5	0.7		1	0.5<=V<1.5	67	1.6%
4	01.09.2010	0:10:00	6.1	8.4	4.2	0.7		2	1.5<=V<2.5	247	5.7%
5	01.09.2010	0:20:00	6.3	7.7	4.8	0.6		3	2.5<=V<3.5	449	10.4%
6	01.09.2010	0:30:00	6.6	8.1	5.1	0.5		4	3.5<=V<4.5	568	13.1%
7	01.09.2010	0:40:00	6.6	8.8	5.2	0.7		5	4.5<=V<5.5	684	15.8%
8	01.09.2010	0:50:00	6.8	8.4	5.4	0.5		6	5.5<=V<6.5	765	17.7%
9	01.09.2010	1:00:00	6.4	7.6	4.8	0.5		7	6.5<=V<7.5	617	14.3%
10	01.09.2010	1:10:00	5.8	7.5	4.6	0.4		8	7.5<=V<8.5	430	10.0%
11	01.09.2010	1:20:00	5.8	6.8	4.6	0.4		9	8.5<=V<9.5	252	5.8%
12	01.09.2010	1:30:00	5.8	7.4	4.6	0.5		10	9.5<=V<10.5	113	2.6%
13	01.09.2010	1:40:00	5.8	7.4	4.5	0.5		11	10.5<=V<11.5	62	1.4%
14	01.09.2010	1:50:00	6	7.6	4.9	0.5		12	11.5<=V<12.5	33	0.8%
15	01.09.2010	2:00:00	5.3	6.8	4.4	0.4		13	12.5<=V<13.5	23	0.5%
16	01.09.2010	2:10:00	4.8	5.7	4	0.3		14	13.5<=V<14.5	10	0.2%
17	01.09.2010	2:20:00	4.9	6.2	4	0.4		15	14.5<=V<15.5	0	0.0%
18	01.09.2010	2:30:00	5	6.3	4.1	0.4		16	15.5<=V<16.5	0	0.0%
19	01.09.2010	2:40:00	4.7	5.7	4	0.3		17	16.5<=V<17.5	0	0.0%
20	01.09.2010	2:50:00	4.2	4.9	3.5	0.2		18	17.5<=V<18.5	0	0.0%
21	01.09.2010	3:00:00	4.2	5.2	3.5	0.3		19	18.5<=V<19.5	0	0.0%
22	01.09.2010	3:10:00	4.2	5.1	3.4	0.3		20	19.5<=V<20.5	0	0.0%
23	01.09.2010	3:20:00	4.5	5.7	3.5	0.4				4320	100%
24	01.09.2010	3:30:00	5	6.3	3.9	0.5					
-	01.09.2010	3:40:00	5.2	6.4	4.1	0.4					
-	01.09.2010	3:50:00	4.8	6.1	3.6	0.5					

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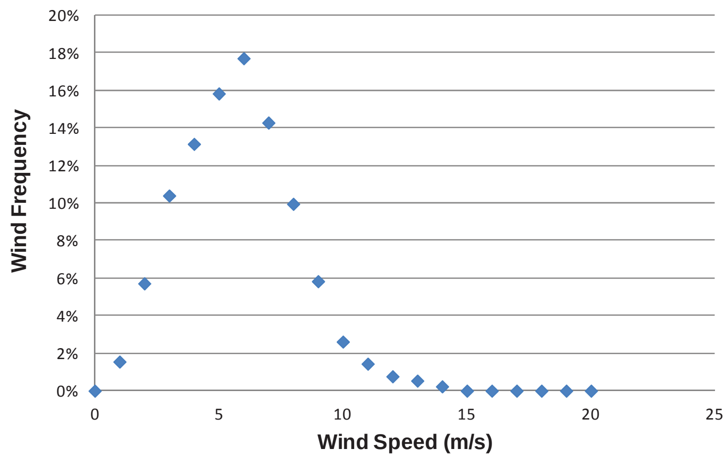
The following figure shows the wind speed frequency. Around 69% of wind speeds are recorded in the range of 4.5 m/s and over.



Prepared by JET

Figure 2.4.1 Wind Speed Frequency

The following spreadsheet is for sorting wind speed data by each wind class.

Table 2.4.3 Spreadsheet for sorting Wind Speed Data

	H	I	J	K
1	Wind Class	Range of Wind Speed (m/s)	No. of Data	Frequency (%)
2	0	0<V<0.5	=COUNTIF(C$3:C$5000,"<0.5")	=J2/$J$23
3	1	0.5<=V<1.5	=COUNTIF(C$3:C$5000,"<1.5")-COUNTIF(C$3:C$5000,"<0.5")	=J3/$J$23
4	2	1.5<=V<2.5	=COUNTIF(C$3:C$5000,"<2.5")-COUNTIF(C$3:C$5000,"<1.5")	=J4/$J$23
5	3	2.5<=V<3.5	=COUNTIF(C$3:C$5000,"<3.5")-COUNTIF(C$3:C$5000,"<2.5")	=J5/$J$23
6	4	3.5<=V<4.5	=COUNTIF(C$3:C$5000,"<4.5")-COUNTIF(C$3:C$5000,"<3.5")	=J6/$J$23
7	5	4.5<=V<5.5	=COUNTIF(C$3:C$5000,"<5.5")-COUNTIF(C$3:C$5000,"<4.5")	=J7/$J$23
8	6	5.5<=V<6.5	=COUNTIF(C$3:C$5000,"<6.5")-COUNTIF(C$3:C$5000,"<5.5")	=J8/$J$23
9	7	6.5<=V<7.5	=COUNTIF(C$3:C$5000,"<7.5")-COUNTIF(C$3:C$5000,"<6.5")	=J9/$J$23
10	8	7.5<=V<8.5	=COUNTIF(C$3:C$5000,"<8.5")-COUNTIF(C$3:C$5000,"<7.5")	=J10/$J$23
11	9	8.5<=V<9.5	=COUNTIF(C$3:C$5000,"<9.5")-COUNTIF(C$3:C$5000,"<8.5")	=J11/$J$23
12	10	9.5<=V<10.5	=COUNTIF(C$3:C$5000,"<10.5")-COUNTIF(C$3:C$5000,"<9.5")	=J12/$J$23
13	11	10.5<=V<11.5	=COUNTIF(C$3:C$5000,"<11.5")-COUNTIF(C$3:C$5000,"<10.5")	=J13/$J$23
14	12	11.5<=V<12.5	=COUNTIF(C$3:C$5000,"<12.5")-COUNTIF(C$3:C$5000,"<11.5")	=J14/$J$23
15	13	12.5<=V<13.5	=COUNTIF(C$3:C$5000,"<13.5")-COUNTIF(C$3:C$5000,"<12.5")	=J15/$J$23
16	14	13.5<=V<14.5	=COUNTIF(C$3:C$5000,"<14.5")-COUNTIF(C$3:C$5000,"<13.5")	=J16/$J$23
17	15	14.5<=V<15.5	=COUNTIF(C$3:C$5000,"<15.5")-COUNTIF(C$3:C$5000,"<14.5")	=J17/$J$23
18	16	15.5<=V<16.5	=COUNTIF(C$3:C$5000,"<16.5")-COUNTIF(C$3:C$5000,"<15.5")	=J18/$J$23
19	17	16.5<=V<17.5	=COUNTIF(C$3:C$5000,"<17.5")-COUNTIF(C$3:C$5000,"<16.5")	=J19/$J$23
20	18	17.5<=V<18.5	=COUNTIF(C$3:C$5000,"<18.5")-COUNTIF(C$3:C$5000,"<17.5")	=J20/$J$23
21	19	18.5<=V<19.5	=COUNTIF(C$3:C$5000,"<19.5")-COUNTIF(C$3:C$5000,"<18.5")	=J21/$J$23
22	20	19.5<=V<20.5	=COUNTIF(C$3:C$5000,"<20.5")-COUNTIF(C$3:C$5000,"<19.5")	=J22/$J$23
23			=SUM(J2:J22)	=SUM(K2:K22)
24				
-				
-				

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If wind data is not available at the project site, wind speed probability can be estimated based on the wind data at the nearest monitoring station or using the model called "Weibull distribution" or "Rayleigh distribution".

Weibull distribution is determined by two parameters, "k" is called the shape factor which describes the form of the distribution, "c" is called the scale factor which represents wind speed. Formulas of the both distributions are as shown below. Rayleigh distribution is a special case of Weibull distribution where “k” is 2. Therefore, to use the Rayleigh distribution, only information of average wind speed is needed. Most manufacturer’s estimates of annual energy output and the performance of manufactured wind turbine are derived from Rayleigh distribution.

Weibull Distribution

$$f(\mathrm{V}) = \frac{k}{c}\left(\frac{\mathrm{V}}{\mathrm{c}}\right)^{k-1} \exp\left[-\left(\frac{\mathrm{V}}{c}\right)^{k}\right]$$

k: shape factor

c: scale factor

Rayleigh Distribution

$$f(\mathrm{V}) = \frac{\pi}{2}\frac{V}{\overline{V}^2}\exp\left[-\frac{\pi}{4}\left(\frac{V}{\overline{V}}\right)^2\right]$$

$\overline{\mathrm{V}} = \text{Average wind speed}$

Table 2.2.4 shows a spreadsheet for estimating wind speed frequency using Rayleigh distribution.

Table 2.4.4 Spreadsheet for Wind Speed Distribution (Rayleigh)

	A	B	C	D	E	F	G	H
1	Weibull shape parameter k	2			Wind Speed bin V (m/s)	from	to	Wind Frequency (f)
2	Weibull scale parameter c	7.7			0	0	0.5	0.422%
3	Wind Speed at anemo. high	6.0 m/s			1	0.5	1.5	3.309%
4	Anemo. Height	30 m			2	1.5	2.5	6.292%
5	Terrain roughness	0.25 m			3	2.5	3.5	8.676%
6	Hub hight	50 m			4	3.5	4.5	10.281%
7	Wind Speed at hub high	6.82 m/s			5	4.5	5.5	11.042%
8					6	5.5	6.5	11.009%
9					7	6.5	7.5	10.317%
10					8	7.5	8.5	9.157%
11					9	8.5	9.5	7.736%
12					10	9.5	10.5	6.240%
13					11	10.5	11.5	4.818%
14					12	11.5	12.5	3.568%
15					13	12.5	13.5	2.536%
16					14	13.5	14.5	1.733%
17					15	14.5	15.5	1.139%
18					16	15.5	16.5	0.720%
19					17	16.5	17.5	0.439%
20					18	17.5	18.5	0.258%
21					19	18.5	19.5	0.146%
22					20	19.5	20.5	0.080%
23					21	20.5	21.5	0.042%
24					22	21.5	22.5	0.021%
25					23	22.5	23.5	0.010%
26					24	23.5	24.5	0.005%
27					25	24.5	25.5	0.002%
28					26	25.5	26.5	0.001%
29								100%

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Figure 2.4.2 shows wind speed distribution at 50 meter above ground level which uses the Rayleigh distribution in the following condition.

- wind speed at 30 meters above ground level: 4.0 m/s
- terrain roughness: 0.25m

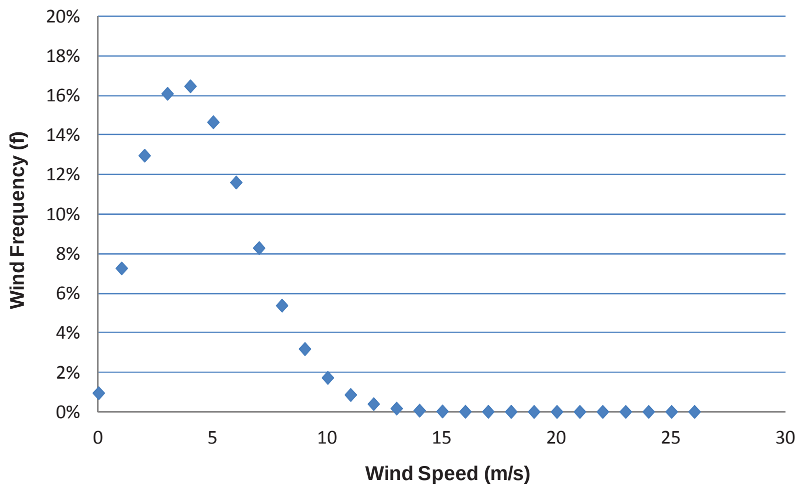

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Figure 2.4.2 Wind Speed Frequency using Rayleigh Distribution

The following spreadsheet Table 2.4.5 and Table 2.4.6 are for estimating wind speed distribution using Rayleigh distribution. It can be applied for Weibull distribution, if Weibull factor of "k" and "c" can be estimated.

In table 2.4.5 wind speed at 50 meters above ground level is estimated using wind speed data at 30 meters above ground level to evaluate wind profile at hub height. For Rayleigh distribution 2 is put for Weibull shape parameter "k".

Table 2.4.5 Spreadsheet for Weibull Parameters and Height Correction

	A	B	C
1	Weibull shape parameter k	2	
2	Weibull scale parameter c	=B7/EXP(GAMMALN(1+1/B1))	
3	Wind Speed at anemo. high	4	m/s
4	Anemo. Height	30	m
5	Terrain roughness	0.25	m
6	Hub hight	50	m
7	Wind Speed at hub high	=B3*(B6/B4)^(B5)	m/s

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Table 2.4.6 Spreadsheet for Weibull Parameters and Height Correction

	A	B	C	D	E	F	G	H
1	Weibull shape para	2			Wind Speed bin V (m/s)	from	to	Wind Frequency (f)
2	Weibull scale parai	=B7/EXP(GAMMALN(1+1/B1))			0	0	0.5	=WEIBULL(G2,$B$1,$B$2,TRUE)-WEIBULL(F2,$B$1,$B$2,TRUE)
3	Wind Speed at ane	4	m/s		1	0.5	1.5	=WEIBULL(G3,$B$1,$B$2,TRUE)-WEIBULL(F3$B$1,$B$2,TRUE)
4	Anemo. Height	30	m		2	1.5	2.5	=WEIBULL(G4,$B$1,$B$2,TRUE)-WEIBULL(F4,$B$1,$B$2,TRUE)
5	Terrain roughness	0.25	m		3	2.5	3.5	=WEIBULL(G5,$B$1,$B$2,TRUE)-WEIBULL(F5,$B$1,$B$2,TRUE)
6	Hub hight	50	m		4	3.5	4.5	=WEIBULL(G6,$B$1,$B$2,TRUE)-WEIBULL(F6,$B$1,$B$2,TRUE)
7	Wind Speed at hub	=B3*(B6/B4)^(B5	m/s		5	4.5	5.5	=WEIBULL(G7,$B$1,$B$2,TRUE)-WEIBULL(F7,$B$1,$B$2,TRUE)
8					6	5.5	6.5	=WEIBULL(G8,$B$1,$B$2,TRUE)-WEIBULL(F8,$B$1,$B$2,TRUE)
9					7	6.5	7.5	=WEIBULL(G9,$B$1,$B$2,TRUE)-WEIBULL(F9,$B$1,$B$2,TRUE)
10					8	7.5	8.5	=WEIBULL(G10,$B$1,$B$2,TRUE)-WEIBULL(F10,$B$1,$B$2,TRUE)
11					9	8.5	9.5	=WEIBULL(G11,$B$1,$B$2,TRUE)-WEIBULL(F11,$B$1,$B$2,TRUE)
12					10	9.5	10.5	=WEIBULL(G12,$B$1,$B$2,TRUE)-WEIBULL(F12,$B$1,$B$2,TRUE)
13					11	10.5	11.5	=WEIBULL(G13,$B$1,$B$2,TRUE)-WEIBULL(F13,$B$1,$B$2,TRUE)
14					12	11.5	12.5	=WEIBULL(G14,$B$1,$B$2,TRUE)-WEIBULL(F14,$B$1,$B$2,TRUE)
15					13	12.5	13.5	=WEIBULL(G15,$B$1,$B$2,TRUE)-WEIBULL(F15,$B$1,$B$2,TRUE)
16					14	13.5	14.5	=WEIBULL(G16,$B$1,$B$2,TRUE)-WEIBULL(F16,$B$1,$B$2,TRUE)
17					15	14.5	15.5	=WEIBULL(G17,$B$1,$B$2,TRUE)-WEIBULL(F17,$B$1,$B$2,TRUE)
18					16	15.5	16.5	=WEIBULL(G18,$B$1,$B$2,TRUE)-WEIBULL(F18,$B$1,$B$2,TRUE)
19					17	16.5	17.5	=WEIBULL(G19,$B$1,$B$2,TRUE)-WEIBULL(F19,$B$1,$B$2,TRUE)
20					18	17.5	18.5	=WEIBULL(G20,$B$1,$B$2,TRUE)-WEIBULL(F20,$B$1,$B$2,TRUE)
21					19	18.5	19.5	=WEIBULL(G21,$B$1,$B$2,TRUE)-WEIBULL(F21,$B$1,$B$2,TRUE)
22					20	19.5	20.5	=WEIBULL(G22,$B$1,$B$2,TRUE)-WEIBULL(F22,$B$1,$B$2,TRUE)
23					21	20.5	21.5	=WEIBULL(G23,$B$1,$B$2,TRUE)-WEIBULL(F23,$B$1,$B$2,TRUE)
24					22	21.5	22.5	=WEIBULL(G24,$B$1,$B$2,TRUE)-WEIBULL(F24,$B$1,$B$2,TRUE)
25					23	22.5	23.5	=WEIBULL(G25,$B$1,$B$2,TRUE)-WEIBULL(F25,$B$1,$B$2,TRUE)
26					24	23.5	24.5	=WEIBULL(G26,$B$1,$B$2,TRUE)-WEIBULL(F26,$B$1,$B$2,TRUE)
27					25	24.5	25.5	=WEIBULL(G27,$B$1,$B$2,TRUE)-WEIBULL(F27,$B$1,$B$2,TRUE)
28					26	25.5	26.5	=WEIBULL(G28,$B$1,$B$2,TRUE)-WEIBULL(F28,$B$1,$B$2,TRUE)
29								=SUM(H2:H28)

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b. Relative Frequency of Wind Direction

If the relative frequency of annual wind direction is **more than 60% in the wind axis**, the wind direction can be considered as stable. Wind axis is defined as the direction of the prevailing wind and the two immediate directions on both sides, and the symmetric directions of these three directions. In total, 6 out of the 16 azimuth angles are designated as the wind axis. The following figure shows an example of wind-axis (SSW, SW, WSW and ENE, NE, NNE)) marked by the red line.

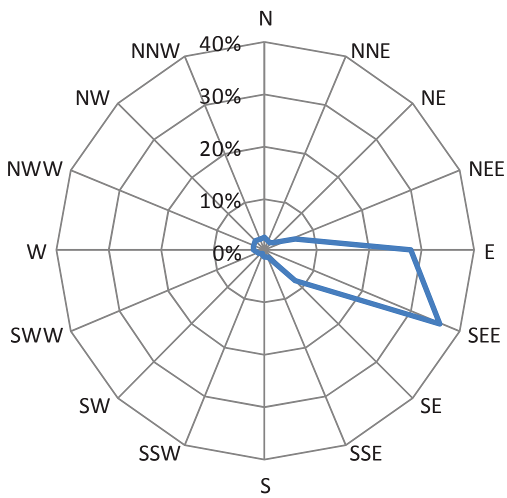

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Figure 2.4.3 Wind Axis

In the following tables, the one of the left shows a sample of datasheet for wind direction which are recorded every 10 minutes. Average wind speed are calculated using functions of spreadsheet such as “AVERAGE(c3:c5000). The table on the right summarizes emergence frequency of wind speeds.

Table 2.4.7 Datasheet and the Result of Wind Direction Evaluation

	A	B	C	D	E	F	G	H	I	J	K
1	date	time	Direction		No.	Direction (degree)			Direction	Data	
2			(40m)							No.	%
3	01.09.2010	0:00:00	107		1	0	<V<	11.25	N	99	2.5%
4	01.09.2010	0:10:00	107		2	11.25	<=V<	33.75	NNE	73	1.8%
5	01.09.2010	0:20:00	106		3	33.75	<=V<	56.25	NE	67	2.2%
6	01.09.2010	0:30:00	110		4	56.25	<=V<	78.75	NEE	170	6.2%
7	01.09.2010	0:40:00	109		5	78.75	<=V<	101.25	E	830	27.7%
8	01.09.2010	0:50:00	109		6	101.25	<=V<	123.75	SEE	1840	36.2%
9	01.09.2010	1:00:00	110		7	123.75	<=V<	146.25	SE	593	7.9%
10	01.09.2010	1:10:00	105		8	146.25	<=V<	168.75	SSE	73	1.4%
11	01.09.2010	1:20:00	100		9	168.75	<=V<	191.25	S	52	1.3%
12	01.09.2010	1:30:00	98		10	191.25	<=V<	213.75	SSW	37	1.1%
13	01.09.2010	1:40:00	92		11	213.75	<=V<	236.25	SW	28	0.7%
14	01.09.2010	1:50:00	90		12	236.25	<=V<	258.75	SWW	61	1.4%
15	01.09.2010	2:00:00	93		13	258.75	<=V<	281.25	W	90	2.4%
16	01.09.2010	2:10:00	101		14	281.25	<=V<	303.75	NWW	97	2.3%
17	01.09.2010	2:20:00	96		15	303.75	<=V<	326.25	NW	99	2.5%
18	01.09.2010	2:30:00	104		16	326.25	<=V<	348.75	NNW	111	2.6%
19	01.09.2010	2:40:00	108		1	348.75	<=V<	360			
20	01.09.2010	2:50:00	95							4320	100%
21	01.09.2010	3:00:00	88								
-	01.09.2010	3:10:00	92								
	01.09.2010	3:20:00	94								

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The following spreadsheet is for sorting wind direction data by each wind direction.

Table 2.4.8 Spreadsheet for sorting Wind Direction Data

	I	J	K
1	Direction	Data	
2		No.	(%)
3	N	=COUNTIF(C$3:C$5000,"<11.25")+(COUNTIF(C$3:C$5000,"<360")-COUNTIF(C$3:J9C$5000,"<348.75"))+(COUNTIF(C$3:C$5000,"=360"))	=J3/$J$20
4	NNE	=COUNTIF(C$3:C$5000,"<33.75")-COUNTIF(C$3:C$5000,"<11.25")	=J4/$J$20
5	NE	=COUNTIF(C$3:C$5000,"<56.25")-COUNTIF(C$3:C$5000,"<33.75")	=J5/$J$20
6	NEE	=COUNTIF(C$3:C$5000,"<78.75")-COUNTIF(C$3:C$5000,"<56.25")	=J6/$J$20
7	E	=COUNTIF(C$3:C$5000,"<101.25")-COUNTIF(C$3:C$5000,"<78.75")	=J7/$J$20
8	SEE	=COUNTIF(C$3:C$5000,"<123.75")-COUNTIF(C$3:C$5000,"<101.25")	=J8/$J$20
9	SE	=COUNTIF(C$3:C$5000,"<146.25")-COUNTIF(C$3:C$5000,"<123.75")	=J9/$J$20
10	SSE	=COUNTIF(C$3:C$5000,"<168.75")-COUNTIF(C$3:C$5000,"<146.25")	=J10/$J$20
11	S	=COUNTIF(C$3:C$5000,"<191.25")-COUNTIF(C$3:C$5000,"<168.75")	=J11/$J$20
12	SSW	=COUNTIF(C$3:C$5000,"<213.75")-COUNTIF(C$3:C$5000,"<191.25")	=J12/$J$20
13	SW	=COUNTIF(C$3:C$5000,"<236.25")-COUNTIF(C$3:C$5000,"<213.75")	=J13/$J$20
14	SWW	=COUNTIF(C$3:C$5000,"<258.75")-COUNTIF(C$3:C$5000,"<236.25")	=J14/$J$20
15	W	=COUNTIF(C$3:C$5000,"<281.25")-COUNTIF(C$3:C$5000,"<258.75")	=J15/$J$20
16	NWW	=COUNTIF(C$3:C$5000,"<303.75")-COUNTIF(C$3:C$5000,"<281.25")	=J16/$J$20
17	NW	=COUNTIF(C$3:C$5000,"<326.25")-COUNTIF(C$3:C$5000,"<303.75")	=J17/$J$20
18	NNW	=COUNTIF(C$3:C$5000,"<348.75")-COUNTIF(C$3:C$5000,"<326.25")	=J18/$J$20
19			
20		=SUM(J3:J19)	=SUM(K3:K19)

Prepared by JET

c. Turbulence Intensity

The intensity of turbulence is greatly affected by topographic features and is therefore difficult to standardize. It is generally within the range of **approximately 0.1-0.3** depending on the topographic features. Candidate locations can be reviewed if the turbulence intensity is larger than that of the IEC standard or it is necessary to consult with manufacturers for the selection of appropriate wind turbines.

$$\text{Intensity of turbulence} = \frac{standard\ deviation\ of\ wind\ speed\ (m/s)}{mean\ wind\ speed\ (m/s)}$$

(3) Evaluation of Energy Output

a. Wind Power Density

Annual wind energy density should be more than **240 W/m^2 at 30 meters above ground level**.

$$P_d = \frac{1}{2}\frac{\rho \sum V^3}{T_0}$$

P_d: Wind Power Density (W/m^2)

ρ: Air Density (kg/m^3)

V: Hourly average wind speed (m/s)

T_0: Number of monitoring hours

b. Capacity Factor of Wind Turbine

Annual capacity factor should be **more than 20%.**

$$\text{Annual Capacity Factor (\%)} = \frac{\text{Annual Energy Output (kWh)}}{\text{Rated Power Output (kW)} \times 8760(\text{hr.})}$$

Utilization factor should be **around 90 to 95%** to account for repair system failures.

Power output correction factor should be 95% in flat regions and 90% in complex terrains.

Annual Power Output (kWh) = Annual Power Output ×Utilization Factor ×Correction Factor

Operation rate expresses the rate of system operation for power generation by hour. With the value that divided the total operation hours of wind turbine by annual hours, it is calculated by accumulation of relative frequency of wind speed from cut-in to cut-out wind speed. When a wind characteristics curve (cumulative relative frequency) is available, it is calculated by the following expressions.

$$\begin{aligned}\text{Operation Rate (\%)} &\\ &= \text{Cumulative relative frequency higher than cut} - \text{in wind speed} \\ &- \text{Cumulative relative frequency higher than cut} - \text{out wind speed}\end{aligned}$$

2.4.2 Estimation of Power Output

Total power output from wind turbines will be assumed based on the available project implementation budget and other considerations such as distance, capacity and main load of the power transmission and distribution grid.

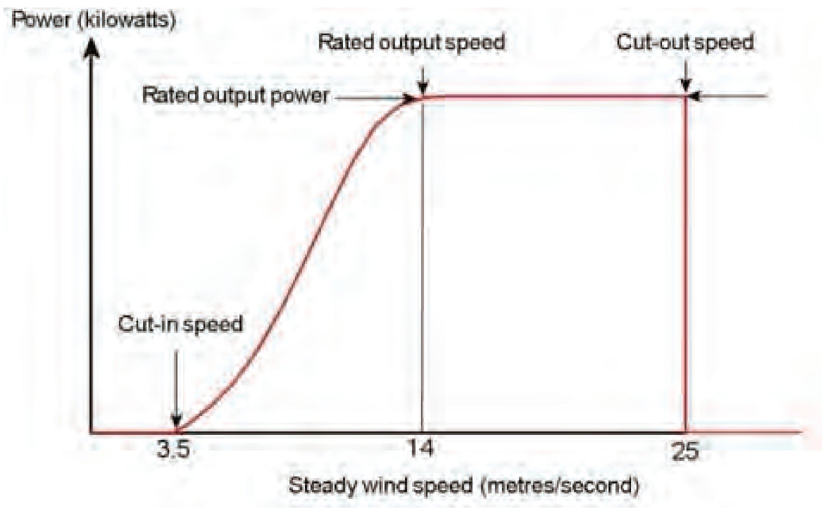
It will be estimated on the basis of the power output curve which will be provided by the manufacturers. Manufacturers estimate the power output of their wind turbines under the standard condition of hub-height wind speed, Rayleigh distribution, air density at sea level and 15 ^{0}C.

When the wind speed is stronger than the cut-in wind speed, the wind turbine starts generating power. The power output is controlled by pitch or stall when wind speeds reach the rated value, and the rotor is stopped to prevent damage and to stop power generation when wind speeds are too high. Figure 2.4.2 shows the typical wind turbine power output with steady wind speed. Cut-in, cut-out and rated output speeds depend on the performance of the wind turbines. In general, the following wind speed values are applied:

Cut-in wind speed : 3～4 m/s

Rated wind speed : 12～16 m/s (dependent on wind turbine performance)

Cut-out wind speed : 24～25 m/s



Source: wind power program (http://www.wind-power-program.com)

Figure 2.4.4 Power Curve of a Typical Wind Turbine

Table 2.4.2 shows the power output from a typical wind turbine. Average power output from wind turbines is calculated using the power curve, by multiplying the power output with wind probability at each wind speed. The following equation shows annual energy output at wind speed Vi (m/s).

$$\text{Annual Energy Output (kWh)} = \sum (P_i \times f_i) \times 8760(\text{hr.})$$

P_i : Power output (kW) at Vi (m/s)
f_i : wind probability (%) at Vi (m/s)

Table 2.4.9 Estimation of Power Output

Wind Class	Range of Wind Speed (m/s)	Wind Speed Probability (f)		Power: (p) (kW)		Net kW (kW)
0	0<V<0.5	0%		0.0		0.00
1	0.5<=V<1.5	2%		0.0		0.00
2	1.5<=V<2.5	6%		0.0		0.00
3	2.5<=V<3.5	10%		0.0		0.00
4	3.5<=V<4.5	13%		0.3		0.03
5	4.5<=V<5.5	16%		0.8		0.13
6	5.5<=V<6.5	18%		1.7		0.29
7	6.5<=V<7.5	14%	✖	2.6	=	0.36
8	7.5<=V<8.5	10%		3.7		0.36
9	8.5<=V<9.5	6%		4.9		0.28
10	9.5<=V<10.5	3%		6.2		0.16
11	10.5<=V<11.5	1%		7.5		0.11
12	11.5<=V<12.5	1%		8.0		0.06
13	12.5<=V<13.5	1%		8.0		0.04
14	13.5<=V<14.5	0%		8.0		0.02
15	14.5<=V<15.5	0%		7.0		0.00
16	15.5<=V<16.5	0%		5.0		0.00
17	16.5<=V<17.5	0%		2.7		0.00
18	17.5<=V<18.5	0%		3.0		0.00
19	18.5<=V<19.5	0%		3.0		0.00
20	19.5<=V<20.5	0%		3.0		0.00
		100%				1.85

Prepared by JET

$$\sum(p_i \times f_i) = 1.85$$

Annual Energy Output = 1.85 (kW) × 8760 (hr.) = 16,206 kWh/Year

Monthly Energy Output = 1.85 (kW) × 720 (hr.) = 1,322 kWh/Month

Daily Energy Output = 1.85 (kW) × 24 (hr.) = 44.4 kWh/day

Capacity Factor = 1.85 / 7.5 = 24.6%

CHAPTER 3. MICRO-SMALL WIND SYSTEMS

3.1 Preparation (Demand Survey, Output Estimation, etc.)

(1) Selection Criteria

A general set of criteria was applied in the primary screening process to identify and select sites for wind power installation. These considerations included:

- Abundant renewable energy potential on site
- Distance from the existing grid line and no immediate plan for connection
- Potential for power demand such as community and business / industrial activities
-

The site for wind power development should be selected in accordance with the following procedures:

Selection of Candidate Area
- Potential
- Electrification Ratio

Site Survey
- Basic Information
- Demand of Community and Business / Industrial Activities

Selection of Candidate Community

1) Potential

The wind potential at of the project candidate site has to be examined. The following information is available in Kenya.

(1) Wind potential map
(ii) Wind monitoring data (MoE&P)

2) Electrification Rates

The community selected for installation of an isolated type small wind turbine should be located in a non-electrified area. Therefore, the area with the lowest electrification ratios should be prioritized.

Electrification rates in various parts of Kenya can be derived from Kenya / County Fact Sheet, 2009.

3) Basic Information

On the basis of the results of the wind potential study and electrification rate, a candidate community can be selected. This data is available from national census reports.

Basic Information includes:

- Pilot Project Site
- Population
- Area (Km^2)
- Population Density

4) Demand

The list below shows the typical demand of electricity in a rural area in Kenya. However, power output from wind and/or wind solar PV hybrid systems is limited and therefore not adequate to operate machines with a large capacity such as welding, refrigerators or water pumping systems. The listed demands are not suitable for isolated autonomous power supply systems by wind and/or solar PV.

- Water Supply System
- Refrigerator
- Welding Machine
- Milling Machine
- Charging Batteries
- Others (Radio, Television, AV equipment, Lighting, etc.)

Demand for a typical power supply station in a rural area in Kenya is estimated as shown in following table. Estimated demands are posho mills, car batteries charging, mobile phones, LED lanterns, LED for lighting and TV. When designing for an un-electrified facility and/or community, power demands have to be estimated at the initial stages of project planning.

Table 3.1.1 Demand of Electrical Equipment

Posho Mill	Capacity	5	kW
	Operational Hours	6	Hours/day
	Consumption	30	kWh/day
Car Batteries	Capacity	70	Ah
		840	Wh
	Number	6	per day
	Discharge	50%	
	Consumption	2.5	kWh/day
Mobile Phones (4V / 1Ah)	Battery	1	Ah
		4.0	Wh
	Number	20	per day
	Discharge	70%	
	Consumption	56	Wh/day
LED Lanterns (6V / 4Ah)	Battery	4	Ah
		24.0	Wh
	Number	15	per day
	Discharge	70%	
	Consumption	252	Wh/day
TV	Capacity	250	W
	Operation	6	Hours/day
	Consumption	1,500	Wh/day
Lighting	LED	10	W
	Operation	10	Hours/day
	Number	15	
	Consumption	1,500	Wh/day
TOTAL 38.1 kWh/day			

Prepared by JET

3.2 Selection of Wind Turbine

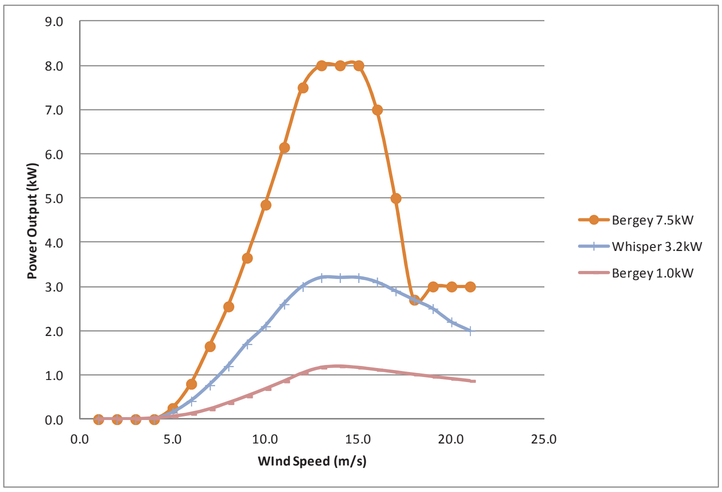
(1) Capacity of Wind Turbine

Selection of the optimum capacity of wind turbine is important, especially for isolated power systems. The wind turbine has to be selected based on the estimated power output from it and demand of the facility. Monthly energy output from a wind turbine, calculated using the lowest monthly wind speed, should be larger than the energy demand of the same month. This monthly he energy output should also be larger than the maximum monthly energy demand.

Condition: Lowest Monthly Wind Speed / Highest Power Demand

Design: Monthly Energy Output > Monthly Energy Demand

If it is difficult to design a system under the above conditions, a hybrid system should be considered. The following shows the performance of small wind turbines.



Net kW	Bergey 1.0kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.00
1.0	0.00
2.0	0.00
3.0	0.02
4.0	0.06
5.0	0.12
6.0	0.22
7.0	0.36
8.0	0.52
9.0	0.68
10.0	0.86
11.0	1.04
12.0	1.17
13.0	1.20
14.0	1.17
15.0	1.12
16.0	1.06
17.0	1.01
18.0	0.96
19.0	0.91
20.0	0.87

Whisper 175 (3.2kW)	Whisper 3.2kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.0
1.0	0.0
2.0	0.0
3.0	0.0
4.0	0.2
5.0	0.4
6.0	0.8
7.0	1.2
8.0	1.7
9.0	2.1
10.0	2.6
11.0	3.0
12.0	3.2
13.0	3.2
14.0	3.2
15.0	3.1
16.0	2.9
17.0	2.7
18.0	2.5
19.0	2.2
20.0	2.0

Net kW	Bergey 7.5kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.0
1.0	0.0
2.0	0.0
3.0	0.0
4.0	0.3
5.0	0.8
6.0	1.7
7.0	2.6
8.0	3.7
9.0	4.9
10.0	6.2
11.0	7.5
12.0	8.0
13.0	8.0
14.0	8.0
15.0	7.0
16.0	5.0
17.0	2.7
18.0	3.0
19.0	3.0
20.0	3.0

Prepared by JET

Figure 3.2.1 Performance of Wind Turbine (1.0 kW to 7.5 kW)

(2) Tower

In terms of power output from a wind turbine, wind speed is the most important factor. If estimated energy output from a wind turbine is too small, tower height can be increased to derive higher energy output. In principal, energy output from a wind turbine is larger when wind speed is higher, and wind speed increases with the tower height. Energy output should therefore be estimated using different heights of the tower.

(3) Availability

The wind turbine must not only fitthe project needs, but must also be available for purchase within the time period of the project. There are several wind turbine manufacturing companies in Kenya, and the use of their wind turbines should be considered when implementing projects in the country.

Table 3.2.1 shows specifications of wind turbines available in Kenya. All the manufactures target micro and small wind turbines.

- Local Manufacturers and Dealers/Importers
- Kijito WindPower Ltd. – Wind Mills manufacturer
- Riwik East Africa Ltd. – Wind Turbines manufacturer
- Craftskills East Africa Ltd. – Wind Turbines manufacturer
- Powergen East Africa Ltd. – Wind Turbines manufacturer
- Kigima High Tech Metal Works – Wind Mills manufacturer
- Davsan Engineering – Wind Mills manufacturer
- Chloride Exide (K) Ltd. – dealer
- Powerpoint systems (E.A.) – dealer
- Davis and Shirtliff - dealer
- Kenital (K) Ltd. – dealer
- Access Energy Ltd. – dealer
- Trusun Ltd. - dealer

Table 3.2.1 Specifications of Wind Turbines Available in Kenya

Brand Names	Manufacturer	Country of Origin	Rated Power Range (W)	Output Voltage (Vdc)	Cut-in Speed (m/s)
Air Breeze, Air X and Whisper	Southwest Windpower	USA	200 – 1000	12/24/48	3-4
Twiga, Simba and Rhino	Windgen/Powergen	Kenya	200 – 1000	12/24	3.2 - 3.5
Taifu	Taizhou Yiju Mech. & Elect Co.	China	400 – 3000	12/24/48	3.0
Craftskills	Craftskills Int.	Kenya	300 - 12000	12/24/48 /98 /360	2-4
Airflow	Riwik E.A.	Kenya	350 – 1000	24 / 48	3

Source: Workshop on Small Wind Energy Systems Training Needs Assessment, JICA / BRIGHT project

(4) Price

The following table shows typical prices of wind turbines available in Kenya. The information was summarized under the JICA / JKUAT renewable energy project for human resource development.

Table 3.2.2 Prices of Wind turbines Available in Kenya

Type	Installed Wind Capacity (W)	Installed PV Capacity (Wp)	Inverter Rating (W)	Installed Battery Capacity (Ah)	Typical Application/ Loads	Typical Facility Where Used	Installed Price (KSh.)
1	200-300	200-300	200-300	200-300	Lighting and small domestic appliances	Domestic households	100,000 to 200,000
2	400	400	400	400		Domestic households	200,000 to 300,000
3	700-900	720	800-1000	600-1000	Lighting, Entertainment, ICT equipment	School, Hospitals, Lodges etc.	300,000 to 400,000
4	1000-1500	800-2000	1200-2000	800-1000	Lighting, Entertainment, ICT equipment	School, Hospitals, Lodges etc.	500,000 to 700,000
5	2000-3000	2000	3000	1200	Lighting, Entertainment, ICT equipment Water pumping	School, Hospitals, Small farms, Lodges etc.	700,000 to 1,000,000

Source: Workshop on Small Wind Energy Systems Training Needs Assessment, JICA / BRIGHT project

3.3 System Configurations

The most suitable wind system configuration can be designed depending on the intended use of electricity. A grid connected system can be applied where there is a stable power grid nearby. On the other hand, an isolated power generation system can be applied in locations that are far from the existing power grid. Power storage systems and wind hybrid systems such as wind - solar PV and wind - diesel can also be considered for isolated power generation systems.

Depending on the condition of the candidate site, the configuration of the wind system can be designed.

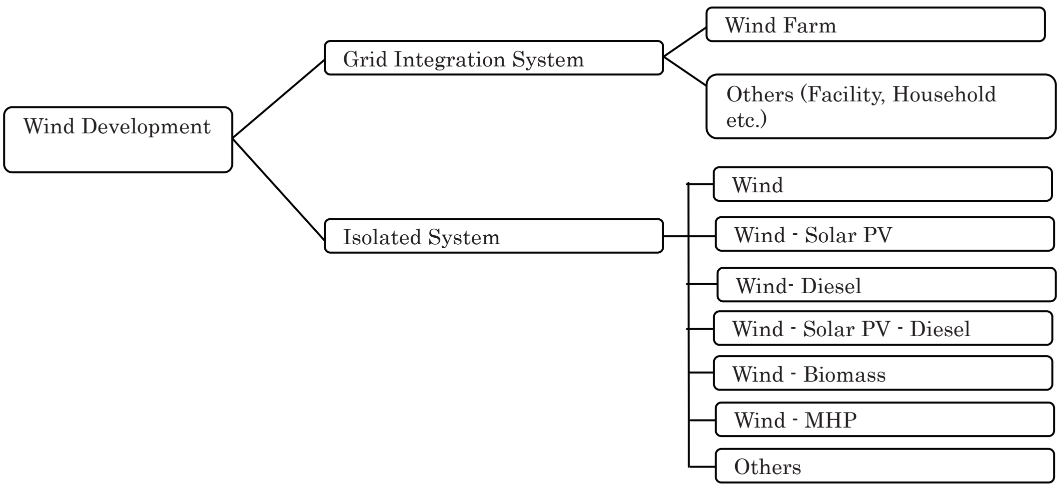


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Figure 3.3.1 Configurations of Wind System

(1) Wind Turbine

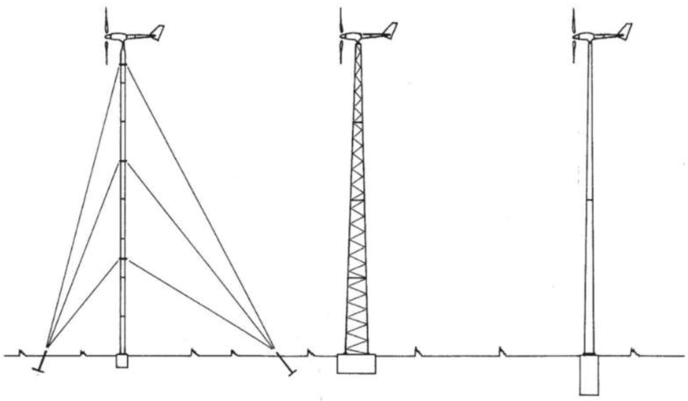
A wind turbine has two functions:

- Collect the wind energy (by blades)
- Convert wind energy into mechanical then electrical energy (by generator)

There are various types and sizes of wind turbines. In general, a wind turbine consists of a rotor, generator and yawing device. A rotor consist of blades, hub and centre shaft.

(2) Tower / Foundation

There are three common types of towers; fixed-guyed, lattice and monopole. The tower must be specially designed with consideration for lateral thrust and turbine weight. It should also be adequately grounded to protect the equipment against lightning damage. Towers can be constructed in Kenya because of their simplicity to design and ease of fabrication locally. Furthermore, the cost of importing is more expensive.



(Fixed-guyed) (Lattice) (Monopole)

Prepared by JET

Figure 3.3.2 Types of Towers

(3) Transmission Wires

Transmission wires are usually made of copper or aluminium. They deliver electricity from the turbine to the BOS then to demand facility. Proper sizing of transmission wires to handle the load, and grounding and safety measures are discussed in the design stage.

(4) Charge Controller

In a battery-based system, a charge controller keeps the batteries properly regulated and safe for the long term. It governs the charge produced by the wind turbine, blocks reverse current and prevents battery overcharge. Overcharging of batteries causes them to wear out more quickly and increases the need for maintenance.

(5) Battery Bank (Storage)

In the plan for an off-grid wind system, a battery bank should be included. However, considerations should be made to minimize the capacity of the battery bank in the initial design, as the cost of battery replacement is expensive.

(6) Inverter

An inverter converts direct current (DC) to alternating current (AC). AC is used by most appliances in households and facilities. However, appliances requiring large electrical power such as irons, electric kettles and refrigerators cannot be used where small wind power generating systems are installed.

(7) Back-up Generator

Sizing a system to cover the worst-case scenario, such as when there is no wind power available for weeks, may require a large and expensive battery bank to be set up. The introduction of a back-up generator should therefore be considered in an off - grid setting.

3.4 Wind – PV Hybrid Systems

(1) Potential

There are many wind monitoring stations in Kenya, installed by the Ministry of Energy and Petroleum in more than 90 sites. This data is useful for estimation of power output from wind turbines. For isolated micro power generation systems, a wind and PV hybrid offers greater reliability than either technology alone. In general, there are seasonal variations of wind potential and solar irradiation in and the two resources are complementary at many mid latitude sites. Wind generation peaks during winter when solar irradiation is at a minimum. At a high wind site, a wind turbine could contribute far more energy to the hybrid system than a PV system of similar size. At a low wind site, energy output from wind and PV could be equal.

A basic design of a Wind-PV Hybrid system for an industrial facility was prepared in the initial stage of JICA project. In the design, Naikarra in Narok County was selected as a candidate site. There is a wind monitoring station in Narok town but not in Naikarra. According to the wind potential map of Kenya, the wind potential in Naikarra is higher than in Narok town. It is essential that a detailed wind potential assessment includes GIS data, a digital map around the monitoring station, a geographical map and wind data at the candidate site. However this data was not available, and the power output was therefore estimated using wind data collected in Narok town.

Table 3.4.1 shows wind speed at 20 meters above ground level, monitored in Narok town. The annual average wind speed is 5.6m/s which is high enough for wind power development. In the monitored period, the highest monthly average wind speed was 6.8m/s and the lowest was 4.4m/s, recorded in April 2011 and December 2010 respectively.

Table 3.4.1 Monthly Average Wind Speed (Narok Town)

Month	Wind Speed (m/s) 20m a.g.l
August, 2010	6.2
September	5.7
October	5.9
November	6.6
December	4.4
January, 2011	4.9
February	4.9
March	5.2
April	6.8
May	6.3
June	4.7
July	5.1
Average	5.6

Source: MoE&P

Table 3.4.2 shows monthly solar irradiation data for Naikarra, obtained from NASA database. The annual average solar irradiation is high, at 6.0kWh/m^2. In the monitored period, the highest monthly average solar irradiation was 6.6kWh/m^2 and the lowest was 5.5kWh/m^2 recorded in February 2011 and July 2011 respectively. However, the irradiation data obtained from NASA database is not accurate for the estimation of energy output from solar PV. It is therefore necessary that solar irradiation is also monitored during wind monitoring, before planning to install solar PV.

Table 3.4.2 Monthly Solar Irradiation (Naikarra)

Month	Solar irradiation (kWh/m^2)
January	6.1
February	6.6
March	6.5
April	6.0
May	5.7
June	5.5
July	5.5
August	5.8
September	6.3
October	6.1
November	5.6
December	5.8
Average	6.0

Source: NASA website

(2) Design of Wind-PV Hybrid System

On the basis of the estimated energy demand in table 3.1.1, appropriate capacity of power generation system will be designed.

There are seasonal and diurnal variations of energy output from wind energy. The appropriate capacity of wind turbine should therefore be calculated based on the minimum monthly wind potential. In Narok, the lowest monthly average wind speed was 4.4 m/s recorded in December. In summary, the power generation system should therefore generate more electricity than the estimated energy demand of 38.1kWh/day, for the lowest wind conditions in December.

The following shows estimated energy output from a solar PV installation with 1kWp capacity.

P= Cp x K x H

Capacity of Solar PV: Cp (W)

Power Output: P (Wh/day)

Sunshine Hours (Solar Irradiation): H(h/day)

Total Design Loss: K

$$K = K_{HD} \times K_{PD} \times K_{PM} \times K_{PA} \times K_{PIX} \times K_{PT}$$

=0.71

Table 3.4.3 Estimated Energy Output of Solar PV (1 kWp)

	Design Factors	Range	Applied
K_{HD}	Annual irradiation deviation	universal constant	0.97
K_{PD}	PV module degrading	0.9 to 0.95	0.9
K_{PM}	PV array load matching	0.9 to 0.98	0.97
K_{PA}	PV array circuit correction	0.95 to 0.98	0.98
K_{PIX}	PV array inclined angle and axis correction	0.9 to 1.0	0.96
K_{PT}	PV temperature factor	32°C	0.89

Prepared by JET

The calculation for temperature correction is shown as follows:

$K_{PT}=1+\alpha_{Pmax}(TM-25)/100$

α_{Pmax} : Temperature coefficient at maximum Power: C-Si: 0.005%/°C)

TM : PV module temperature (weighted average)

$TM=T_{AV}+\Delta T$

T_{AV} : Monthly average temperature

ΔT : PV module temperature rise (weighted average)

Therefore, estimated power output of solar PV is as shown in table 3.4.4.

Table 3.4.4 Estimated Power Output of Solar PV (1 kWp)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Irradiation (kWh/m^2/day)	6.1	6.6	6.5	6.0	5.7	5.5	5.5	5.8	6.3	6.1	5.6	5.8	6.0
Output (kWh)/kWp)	4.3	4.7	4.6	4.2	4.0	3.9	3.9	4.1	4.5	4.3	4.0	4.1	4.2

Prepared by JET

Table 3.4.5 shows results of estimated energy output from a wind turbine with 3kW rated power output. The table shows that net energy output in December is the lowest.

Table 3.4.5 Estimated Net Energy Output (kW) From Wind (3 kW)

Wind Speed Bin (m/s)	Power (W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.2	0.02	0.03	0.02	0.01	0.01	0.03	0.02	0.01	0.02	0.01	0.01	0.03	0.02
5	0.4	0.05	0.06	0.05	0.04	0.04	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.05
6	0.8	0.09	0.10	0.10	0.08	0.11	0.11	0.14	0.11	0.12	0.12	0.09	0.10	0.11
7	1.2	0.14	0.14	0.14	0.14	0.19	0.18	0.21	0.24	0.21	0.19	0.15	0.10	0.17
8	1.7	0.16	0.19	0.19	0.25	0.23	0.21	0.21	0.28	0.24	0.25	0.18	0.11	0.21
9	2.1	0.15	0.17	0.19	0.32	0.30	0.13	0.15	0.26	0.21	0.25	0.26	0.11	0.21
10	2.6	0.12	0.12	0.18	0.30	0.26	0.05	0.08	0.30	0.15	0.15	0.29	0.08	0.18
11	3.0	0.08	0.05	0.10	0.21	0.18	0.04	0.04	0.13	0.08	0.13	0.23	0.07	0.11
12	3.2	0.04	0.04	0.05	0.14	0.05	0.01	0.01	0.03	0.05	0.07	0.17	0.04	0.06
13	3.2	0.02	0.02	0.01	0.08	0.02	0.00	0.00	0.00	0.02	0.04	0.08	0.02	0.03
14	3.2	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.01
15	3.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
16	2.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	2.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	2.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	2.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	kW	0.89	0.90	1.03	1.60	1.40	0.81	0.92	1.40	1.18	1.27	1.52	0.73	1.16

Prepared by JET

Further, air density in Narok is lower than standard condition. It should be considered and a safety margin incorporated in the estimation.

Table 3.4.6 Estimated Energy Output from Wind (3 kW)

Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Net kW	0.89	0.90	1.03	1.60	1.40	0.81	0.92	1.40	1.18	1.27	1.52	0.73	1.16
kW	0.63	0.64	0.73	1.13	0.99	0.57	0.65	0.99	0.83	0.89	1.08	0.52	0.82
Daily (kWh/day)	15.1	15.3	17.5	27.2	23.7	13.8	15.6	23.7	20.0	21.5	25.8	12.4	19.6
Monthly(kWh/Mo)	469	428	542	815	734	413	483	736	600	666	775	384	7,171

Air density (Monitored in Narok)	0.9622
Air density (Std. test condition)	1.226
Air density Ratio	78%
Safety Margin	10%

Prepared by JET

Table 3.4.7 shows estimated energy output from a wind (6kW) and solar PV (6kW) hybrid system. The minimum monthly energy output is expected to be 39.8 kWh/day in December, which is still adequate to cover the estimated energy demand in Table 3.1.1.

Table 3.4.7 Monthly Energy Output (Wind 6 kW, Solar PV 6 kW)

Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Wind (6kW)	30.2	30.6	35.0	54.3	47.3	27.6	31.2	47.5	40.0	43.0	51.7	24.8	39.3
PV (6kW)	26.0	28.0	27.6	25.3	24.2	23.5	23.3	24.7	26.8	25.9	23.8	24.8	25.3
Output (kWh/day)	56.2	58.6	62.6	79.6	71.5	51.1	54.5	72.2	66.8	68.8	75.5	49.5	64.6
Output (kWh/Month)	1,742	1,641	1,940	2,389	2,218	1,533	1,689	2,239	2,005	2,133	2,265	1,535	23,584
Total Loss	Power Output End-Use (kWh/day)												
80%	45.2	47.1	50.3	64.0	57.5	41.1	43.8	58.1	53.7	55.3	60.7	39.8	52.0

Loss	
Distribution	95%
Inverter	90%
Battery	95%
C/C	99%

Prepared by JET

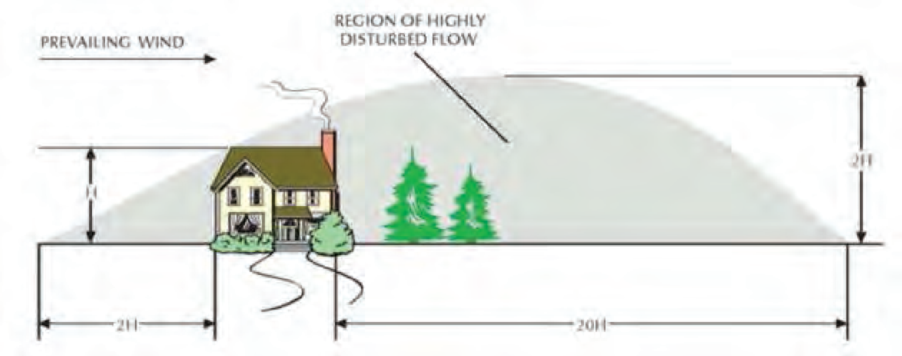
3.5 Design Concept

(1) Siting

Wind turbines will not generate electricity everywhere. They have to be installed in windy sites, therefore making site selection the most important. Windy areas can be identified using a wind potential map or monitored data. At the candidate site for the project, the most suitable installation site should be selected considering wind potential, geographical conditions and social conditions.

Wind turbines should always be located as far away as possible from obstructions such as trees and buildings amongst others in order to minimize the effect of turbulence and maximize exposure to the wind. Turbulence is caused by the wake from obstructions in the wind's path, and may damage modern wind turbines as they have long slender blades rotating at high speeds. Turbulence can therefore shorten the life of wind turbines. In addition, obstructions such as buildings and trees drastically reduce the energy available to a wind turbine.

The tower should also be located far enough upwind and or downwind to avoid the turbulent zones around nearby obstructions as shown in Figure 3.5.1. Wind speed decreases and turbulence increases in the vicinity of obstructions. The effects of turbulence are most pronounced downwind but also occur upwind as the air piles up in front of the obstruction. The flow over buildings or trees in a shelter belt is distributed in a similar manner.



Source: Wind Power

Figure 3.5.1 Turbulent Zone around Obstructions

(2) Power Cable Routing

Power cable routes will be considered once the installation site for the wind turbine is determined. At this stage, it is necessary to anticipate any problems that may develop later as it is obviously easier to avoid the problems than to solve them later. Ideally, the power supply from wind turbines will enter the demand building or be connected to the grid line within a short distance. However, if the wind turbine has to be installed far from the demand building, the best route for laying the power cable should be considered.

CHAPTER 4. WIND-DIESEL HYBRID SYSTEM

4.1 Preparation (Demand Survey, Output Estimation, etc.)

Power demands should be studied to design an appropriate wind and diesel hybrid system. Table 4.1.1 shows typical power potential of electrical equipment and hours of use. Electrical demand is estimated using the power potential of electrical equipment and operational hours. The power potential of equipment should be confirmed in demand survey.

Table 4.1.1 Potential of Electrical Equipment

Electrical Equipment (AC)	Power (W)	Hours of Use
Television (Colour, 30 inch)	70 -150	3-8
DVD	20 - 40	1-2
TV, DVD - stand by	10	21 – 16
Light (LED)	10	3-8
Computer (Laptop)	20 - 150	1-6
Printer (Inkjet)	15 - 30	0.5 – 1.0
Blender	250	< 0.5
Radio	5 - 50	1 - 8
Refrigerator	150 - 600	24

Prepared by JET

Table 4.1.2 shows the estimated power demand for a household.

Table 4.1.2 Estimation of Power Demand (Household)

Electrical Equipment	Potential (W)	Hours (h/day)	Energy Consumption (Wh/day)
Light 1 (LED)	10	10	100
Light 2 (LED)	10	6	60
Light 3 (LED)	10	6	60
Television	100	4	400
Computer	150	2	300
Radio	30	8	240
TOTAL	310	36	1160

Prepared by JET

Different facilities have different power demand. For example, a health clinic may need a vaccine refrigerator while it may be nice for café to have a television for customers. In offices, it may be more essential for workers to use computers and printers for their work. It is therefore necessary to estimate energy demand of different types of facilities which will be electrified by a wind - diesel hybrid system. In an un-electrified rural community, the future energy demand of the community should be estimated.

Demand can be divided into three main categories; households, economic activities and public facilities. Future energy demand should therefore be estimated for each type of facility.

- Households
- Economic Activities (Café, Restaurant, Shop, Posho mill, etc.)
- Public Facilities (Health Clinic, School, Office, Public Well, etc.)

For each facility, the following have to be estimated by the field inventory survey and then used to estimate power demand of the covered area.

- Potential of Power Equipment (watts)
- Hours of Use (hours / day)

The following is a sample of the estimated power demand of a community. If there is adequate time and personnel to investigate power demand of a community, inventory survey of end users should be conducted. Power demand for all facilities should be accumulated to estimate the demand of a community. At first, the number of existing facilities should be determined, and used to estimate which and how many facilities use electricity in every hour. Table 4.1.3 shows the number of facilities using electricity by hour.

Table 4.1.3 Number of Facilities Using Electricity (Nos.)

Time	Households	Hotel	Poshomill	Community	School	Dispensary
0	30	1	0	1	1	1
1	30	1	0	1	1	1
2	30	1	0	1	1	1
3	30	1	0	1	1	1
4	30	1	0	1	1	1
5	30	1	0	1	1	1
6	30	1	0	1	1	1
7	45	2	3	1	1	1
8	45	2	3	1	1	1
9	45	3	3	1	1	1
10	45	3	3	1	1	1
11	45	3	3	1	1	1
12	45	3	3	1	1	1
13	45	2	3	1	1	1
14	45	2	3	1	1	1
15	45	2	3	1	1	1
16	45	3	3	1	1	1
17	45	3	3	1	1	1
18	50	2	1	1	1	1
19	50	2	1	1	1	1
20	50	2	1	1	1	1
21	45	2	0	1	1	1
22	35	2	0	1	1	1
23	30	1	0	1	1	1

Prepared by JET

The following table shows estimated power demand of each facility by hour.

Table 4.1.4 Power Demand of Facilities (kW)

Time	Households	Hotel	Poshomill	Community	School	Dispensary
0	0.10	0.03	0.00	0.00	0.03	0.03
1	0.06	0.06	0.00	0.00	0.03	0.03
2	0.06	0.06	0.00	0.00	0.03	0.03
3	0.03	0.03	0.00	0.00	0.03	0.03
4	0.03	0.03	0.00	0.00	0.03	0.03
5	0.03	0.03	0.00	0.00	0.03	0.03
6	0.06	0.06	0.00	0.00	0.03	0.03
7	0.08	0.08	0.00	0.00	0.05	0.05
8	0.10	0.10	0.80	0.00	0.30	0.05
9	0.10	0.10	0.80	0.10	0.30	0.10
10	0.10	0.10	0.80	0.10	0.30	0.12
11	0.10	0.10	0.80	0.10	0.30	0.12
12	0.12	0.10	0.00	0.10	0.30	0.12
13	0.15	0.10	0.00	0.10	0.30	0.10
14	0.15	0.10	0.80	0.10	0.30	0.10
15	0.10	0.10	0.80	0.10	0.30	0.12
16	0.10	0.10	0.80	0.10	0.30	0.12
17	0.12	0.15	0.80	0.10	0.60	0.12
18	0.12	0.18	0.00	0.00	0.60	0.10
19	0.15	0.20	0.00	0.00	0.60	0.08
20	0.20	0.20	0.00	0.00	0.60	0.03
21	0.20	0.20	0.00	0.00	0.60	0.03
22	0.18	0.18	0.00	0.00	0.40	0.03
23	0.15	0.15	0.00	0.00	0.20	0.03

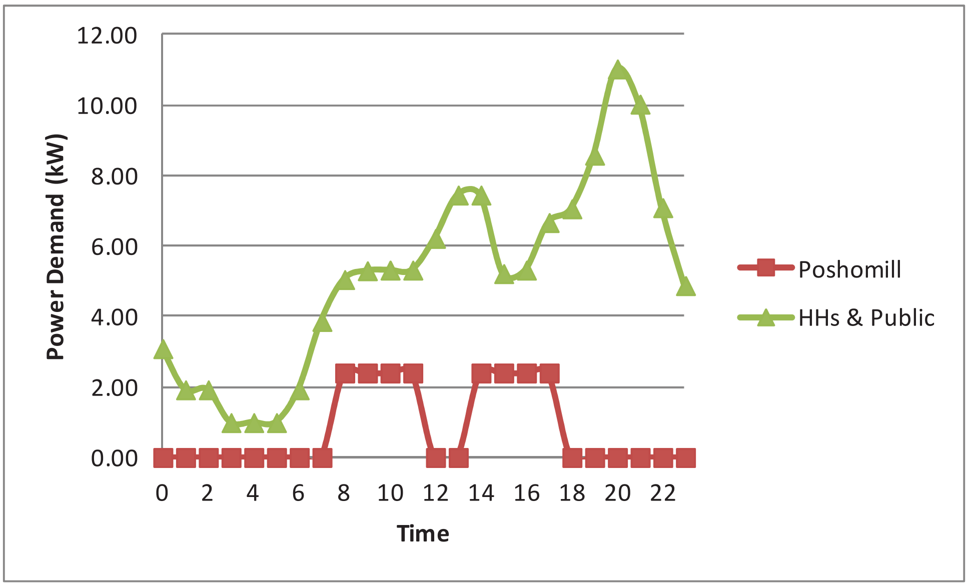
Prepared by JET

The table below shows estimated power demand of a community. In general, power demand of a rural community and its public facilities are not large. On the other hand, power demand of a Posho mill is large compared to the demand of other facilities. The table below shows total energy demand of a community, estimated at 142.87 kWh/day. Figure 4.1.1 shows estimated power demand curve. For households and public institutions, power demand is high in the evening and low in the early morning. Power consumption of a posho mill as a rural micro – industry is large during daytime. Possibility of increases in the number of posho mills or number of posho mill businesses should be considered, based on the project site survey.

Table 4.1.5 Power Demand of a Community (kW)

Time	Households	Hotel	Poshomill	Community	School	Dispensary	Total Demand
0	3.00	0.03	0.00	0.00	0.03	0.03	3.09
1	1.80	0.06	0.00	0.00	0.03	0.03	1.92
2	1.80	0.06	0.00	0.00	0.03	0.03	1.92
3	0.90	0.03	0.00	0.00	0.03	0.03	0.99
4	0.90	0.03	0.00	0.00	0.03	0.03	0.99
5	0.90	0.03	0.00	0.00	0.03	0.03	0.99
6	1.80	0.06	0.00	0.00	0.03	0.03	1.92
7	3.60	0.16	0.00	0.00	0.05	0.05	3.86
8	4.50	0.20	2.40	0.00	0.30	0.05	7.45
9	4.50	0.30	2.40	0.10	0.30	0.10	7.70
10	4.50	0.30	2.40	0.10	0.30	0.12	7.72
11	4.50	0.30	2.40	0.10	0.30	0.12	7.72
12	5.40	0.30	0.00	0.10	0.30	0.12	6.22
13	6.75	0.20	0.00	0.10	0.30	0.10	7.45
14	6.75	0.20	2.40	0.10	0.30	0.10	9.85
15	4.50	0.20	2.40	0.10	0.30	0.12	7.62
16	4.50	0.30	2.40	0.10	0.30	0.12	7.72
17	5.40	0.45	2.40	0.10	0.60	0.12	9.07
18	6.00	0.36	0.00	0.00	0.60	0.10	7.06
19	7.50	0.40	0.00	0.00	0.60	0.08	8.58
20	10.00	0.40	0.00	0.00	0.60	0.03	11.03
21	9.00	0.40	0.00	0.00	0.60	0.03	10.03
22	6.30	0.36	0.00	0.00	0.40	0.03	7.09
23	4.50	0.15	0.00	0.00	0.20	0.03	4.88
	109.30	5.28	19.20	0.90	6.56	1.63	142.87

Prepared by JET

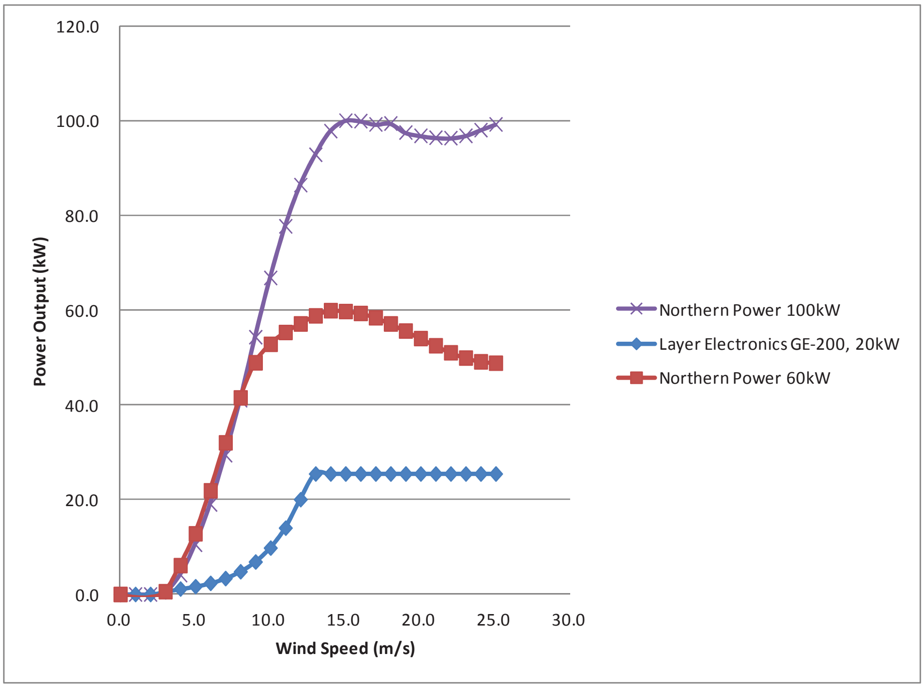


Prepared by JET

Figure 4.1.1 Estimated Demand Curve

4.2 Selection of Wind Turbine

Figure 4.2.1 and Figure 4.2.2 show the performance of wind turbines between 20kW and 2500kW. On the basis of performance curve of wind turbines, energy output from wind turbines should be estimated.



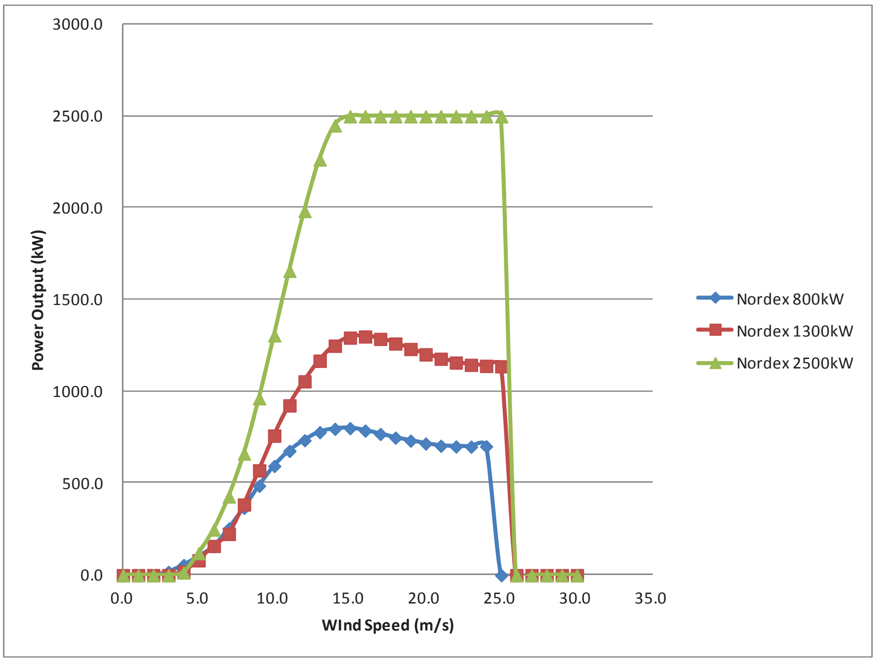
Net kW	Layer Electronics GE-200, 20kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0	0
1	0
2	0
3	0.6
4	1.2
5	1.7
6	2.4
7	3.4
8	4.8
9	6.9
10	9.8
11	14.0
12	20.0
13	25.4
14	25.4
15	25.4
16	25.4
17	25.4
18	25.4
19	25.4
20	25.4
21	25.4
22	25.4
23	25.4
24	25.4
25	25.4

Net kW	Northern Power 60kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0
1.0	-0.6
2.0	-0.6
3.0	0.6
4.0	6.1
5.0	12.8
6.0	21.9
7.0	32.0
8.0	41.5
9.0	48.9
10.0	52.8
11.0	55.3
12.0	57.1
13.0	58.8
14.0	59.9
15.0	59.7
16.0	59.3
17.0	58.4
18.0	57.1
19.0	55.6
20.0	54.0
21.0	52.5
22.0	51.0
23.0	49.9
24.0	49.1
25.0	48.8

Net kW	Northern Power 100kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.0
1.0	0.0
2.0	0.0
3.0	0.5
4.0	4.1
5.0	10.5
6.0	19.0
7.0	29.4
8.0	41.0
9.0	54.3
10.0	66.8
11.0	77.7
12.0	86.4
13.0	92.8
14.0	97.8
15.0	100.0
16.0	99.9
17.0	99.2
18.0	99.4
19.0	97.5
20.0	96.8
21.0	96.4
22.0	96.3
23.0	96.8
24.0	98.0
25.0	99.2

Prepared by JET

Figure 4.2.1 Performance of Wind Turbine (20 kW to 100 kW)



Net kW	Nordex 800kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.0
1.0	0.0
2.0	0.0
3.0	18.0
4.0	55.0
5.0	102.0
6.0	157.0
7.0	255.0
8.0	367.0
9.0	487.0
10.0	595.0
11.0	677.0
12.0	735.0
13.0	779.0
14.0	797.0
15.0	801.0
16.0	788.0
17.0	769.0
18.0	749.0
19.0	733.0
20.0	717.0
21.0	705.0
22.0	701.0
23.0	700.0
24.0	702.0
25.0	0.0
26.0	0.0

Net kW	Nordex 1300kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.0
1.0	0.0
2.0	0.0
3.0	0.0
4.0	20.0
5.0	81.0
6.0	159.0
7.0	225.0
8.0	385.0
9.0	571.0
10.0	760.0
11.0	925.0
12.0	1056.0
13.0	1168.0
14.0	1250.0
15.0	1294.0
16.0	1300.0
17.0	1287.0
18.0	1262.0
19.0	1232.0
20.0	1203.0
21.0	1179.0
22.0	1158.0
23.0	1146.0
24.0	1140.0
25.0	1138.0
26.0	0.0
27.0	0.0
28.0	0.0
29.0	0.0
30.0	0.0

Net kW	Nordex 2500kW
Wind Speed Bin: V (m/s)	Power: p (kW)
0.0	0.0
1.0	0.0
2.0	0.0
3.0	0.0
4.0	15.0
5.0	120.0
6.0	248.0
7.0	429.0
8.0	662.0
9.0	964.0
10.0	1306.0
11.0	1658.0
12.0	1984.0
13.0	2264.0
14.0	2450.0
15.0	2500.0
16.0	2500.0
17.0	2500.0
18.0	2500.0
19.0	2500.0
20.0	2500.0
21.0	2500.0
22.0	2500.0
23.0	2500.0
24.0	2500.0
25.0	2500.0
26.0	0.0
27.0	0.0
28.0	0.0
29.0	0.0
30.0	0.0

Prepared by JET

Figure 4.2.2 Performance of Wind Turbine (800 kW to 2500 kW)

4.3 System Configuration

Wind and diesel power plants can be used in combination to supply power in an autonomous system where connection to the national grid is either impossible or too expensive due to the length of transmission line. Diesel generators provide power when needed, while wind turbines generate power to reduce diesel fuel consumption. In a diesel mini-grid, it is necessary to supply consumers with electricity at a controlled voltage and frequency, equivalent to the national grid.

The frequency of a power system is determined by the balance between input power from the generators and power taken from the load. If the generator output exceeds the load demand, surplus power will increase the rotational speed of the generators and hence increase the system frequency. Conversely, if the load demand exceeds the power available from the generator, the frequency will reduce. In a wind - diesel system, surplus power will produce a rapid rise in the rotational speed of the generators and an increase in system frequency. Therefore, if the load is determined by consumer's demand, the generator should follow the load or energy storage should be used.

The control of frequency in a wind - diesel system is likely to be difficult and expensive, even though it may achieve significant savings in diesel fuel consumption. Energy storage devices such as batteries and flywheels amongst others could be considered. However, storage adds considerable expense and complexity to any wind - diesel system.

Important parameters for design of wind - diesel hybrid system are as shown below.

- Wind profile
- Demand curve of existing diesel generator
- Correlation between wind pattern and demand curve
- Power quality requirement
- Ease of maintenance and availability of spare parts and consumable supplies

Among the problems of integrating a wind turbine and existing diesel generator are voltage and frequency control, frequent stops and starts of the diesel generator, utilization of surplus energy, and the use and operation of new technologies. These problems vary the wind penetration value; a common measure of performance for wind - diesel systems which shows the ratio between Wind Power and Total Power delivered. For example, 30% wind penetration implies that 30% of the system power comes from wind. Wind penetration values can be either peak or long term. It is important for REA and MoE&P staff to estimate the penetration ratio of wind - diesel hybrid systems in the planning stage of the project. The ratio is a key factor in deciding specifications of the project, and especially determining the necessity of stabilizer.

Table 4.3.1 Penetration Class of Wind - Diesel Systems

Penetration Class	Operating Characteristics	Power Penetrations	Energy Penetration
LOW	• Diesel runs full-time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
MEDIUM	• Diesel runs full-time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed • Requires relatively simple control system	50%–100%	20%–50%
HIGH	• Diesel may be shut down during high wind availability • Auxiliary components are required to regulate voltage and frequency • Requires sophisticated control system	100%–400%	50%–150%

Source: Wind Energy: Renewable Energy and Environment, Second Edition

Estimation of Wind - Diesel Penetration Ratio

Case-1: Installation of wind turbine at existing diesel power station

(1) Calculation of average penetration ratio

1) Study the operational record of existing diesel generator and calculate the following information.
   - Annual Energy Output (kWh/year)
   - Monthly Energy Output (kWh/month)
   - Diurnal Energy Output (kWh/day)

2) Estimate power output of candidate wind turbine to calculate the following information.
   - Annual Energy Output (kWh/year)
   - Monthly Energy Output (kWh/month)
   - Diurnal Energy Output (kWh/day)

3) Calculate average penetration ratio

$$\text{Annual Energy Penetration} = \frac{\text{Annual Wind Energy Output (kWh)}}{\text{Annual Primary Energy Demand (kWh)}} \times 100(\%)$$

(2) Calculation of Instantaneous Penetration Ratio

Instantaneous penetration ratio becomes large when wind blows strong at small power demand. For example, the penetration ratio tends to become large at midnight as the wind may blow strong when power demand is small as well.
To calculate instantaneous penetration ratio:

1) Study operational records of diesel generator to determine the following information.
   - 10 smallest power outputs and their recorded time (kW @ time)
   - Identify wind speeds (m/s) at the recorded times, then estimate power output (kW)
   - Calculate instantaneous wind power penetration (%)

2) Study wind data over one year to determine the following information
   - 10 largest instantaneous wind speeds and their recorded time (m/s @ time)
   - Estimate power outputs at the wind speeds above (kW @ time)
   - Identify diesel power outputs at the recorded time (kW@time)
   - Calculate instantaneous wind power penetration (%)

3) In both of the cases indicated above, calculate power penetration ratio using following formula.

$$\text{Power Penetration} = \frac{\text{Wind Power Output (kW)}}{\text{Diesel Power Output (kW)} + \text{Wind Power Output (kW)}} \times 100(\%)$$

Case-2: New Installation

(1) Estimation of Power Demand

Power demand of the diesel power station should be estimated at the planning stage based on the demand of domestic households and public facilities such as schools, dispensaries and offices. The procedure for estimating total energy output is explained in Chapter 4.1.

(2) Penetration Ratio

For a newly constructed power generation facility using a wind - diesel hybrid system, diesel generator capacity should be decided first. At an isolated power station, diesel generator is the most important component to ensure electricity supply is stable. Considering penetration ratio in addition to estimated power demand allows for optimum capacity of wind turbine to be selected.

Wind turbines with low penetration can be added to existing diesel power generation for large communities with few problems because the wind segment is essentially a fuel saver. Some olutions for high wind penetration are the use of flywheels r battery storage. Based on data for "Alaska Isolated Wind - Diesel system", a dump load or storage is needed to reach predicted energy production from the wind turbine even for low penetration. Otherwise, the capacity factors will be lower than predicted. Table 4.3.2 shows a sample of wind - diesel hybrid systems with penetration ratios.

Table 4.3.2 Sample of Wind - Diesel Hybrid Generation

	Diesel	Wind	Penetration Ratio
Low Penetration	100 kW (100kW x 50% x 8760 hr.= 438,000 kWh)*1 Minimum Demand 25kW	25 kW (25 kW x 25% x 8760 hr. = 54,750 kWh) Maximum Power 25 kW	Energy Penetration; 11 % $\left(\frac{54{,}750}{438{,}000+54{,}750}\right)$ Power Penetration; 50 % $\left(\frac{25}{25+25}\right)$
Middle Penetration	100 kW Minimum Demand 25 kW	50 kW (50 kW x 25% x 8,760 hr. = 109,500 kWh) Maximum Power 50kW	Energy Penetration; 20 % $\left(\frac{109{,}500}{438{,}000+109{,}500}\right)$ Power Penetration; 67 % $\left(\frac{50}{25+50}\right)$
High Penetration (Battery, flywheel, etc.)	100 kW (shutdown @ high wind) Minimum Demand 25kW	150 kW (150 kW x 25% x 8760 hr. = 328,500 kWh) Storage: 300 kWh (50kW x 6hr x 365 day) Maximum Power 150kW	Energy Penetration; 57 % $\left(\frac{328{,}500+109{,}500}{438{,}000+328{,}500}\right)$ Power Penetration; 114 % $\left(\frac{150+50}{25+150}\right)$

*1: Annual Energy Output (kWh/year) = Capacity of Wind Turbine (kW) x Capacity Factor (25%) x Annual hours (8760)

Prepared by JET

<u>Low Wind Penetration</u>
The low wind penetration system is the simplest and easiest wind - diesel hybrid system to construct and operate. There is no secondary load controller, no energy storage such as a battery bank and no change to existing diesel generator. However, when compared to a higher wind penetration system, avoided diesel fuel consumption is minimal. One very significant advantage of a low wind penetration

approach is that it allows the operating company to gain experience in wind - diesel operation before potentially expanding the system to higher wind penetration.

Medium Wind Penetration
The concept of medium wind penetration is to allow instantaneous penetrations above 50%. When using a large wind penetration system, it becomes harder for the diesel generators to tightly regulate system voltage and maintain adequate power balance. However, there are options to ensure that the high-power-quality requirements of the system are maintained, even when half of the energy is provided by wind. Some of these options include power reduction capabilities within the wind turbine controller, the inclusion of a secondary load to ensure that no more than a specified amount of energy is generated by wind, installation of capacitor banks to correct the power factor, and even the use of advanced power electronics to allow real-time power specification.

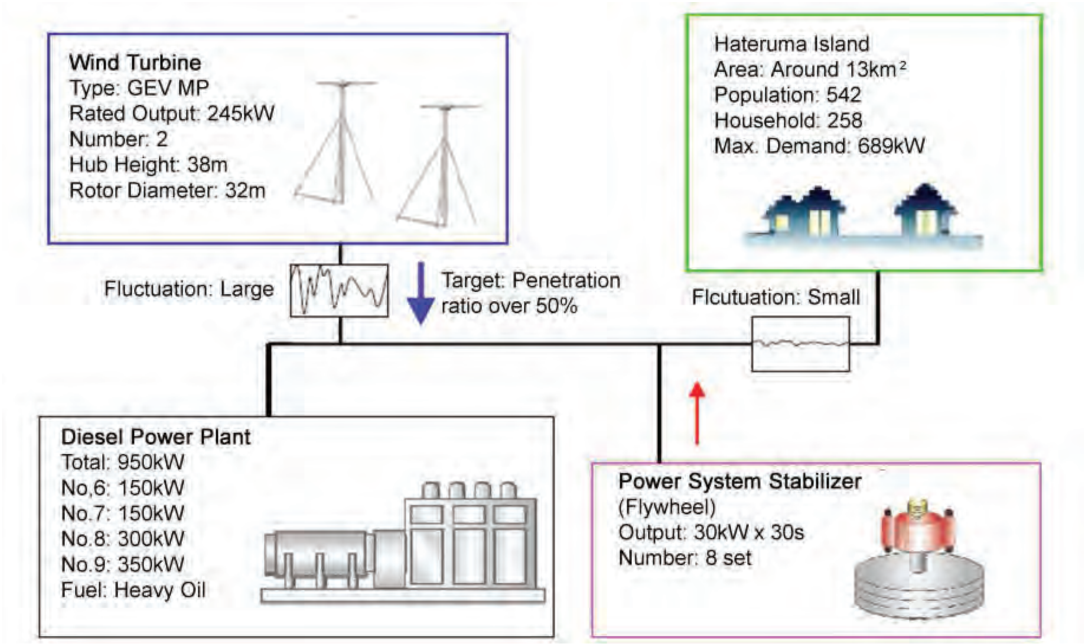
High Wind Penetration
The principle of high-penetration systems is that ancillary equipment is installed in addition to a large amount of wind capacity (up to 300% of the average power requirement), so that diesel can be shut off completely when there is an abundance of wind power production. Any instantaneous wind power production higher than the required electrical load is supplied to a variety of controllable secondary loads. In these systems, synchronous condensers, load banks, dispatchable loads (including storage in the form of batteries or flywheel systems), power converters, and advanced system controls are used to ensure power quality and system integrity.

4.4 Design Concept

4.4.1 Power Stabilizer

The following figure shows the system diagram for a wind - diesel hybrid system in Hateruma Island, in Southern Japan. The types of wind turbines installed in Hateruma Island are similar to those installed in Marsabit wind – diesel hybrid system, from the same manufacturers.

On the island, the penetration ratio is targeted at over 50%, and flywheels are therefore installed to stabilize fluctuation caused by wind turbines. Maximum power demand of the island is almost the same as that of Marsabit. Currently, power from wind turbines is not fully supplied at Marsabit wind - diesel station, as only one wind turbine is being operated. In addition, the energy produced is not being supplied from midnight to morning when power demand is low because there is no power storage such as a battery bank or flywheel. Therefore, penetration ratio becomes too high to operate the power generation system under normal conditions. The costs of battery bank and flywheel are likely to be expensive. However, they should be considered if there is enough wind potential for power generation during low power demand.



Source: Okinawa Enetech

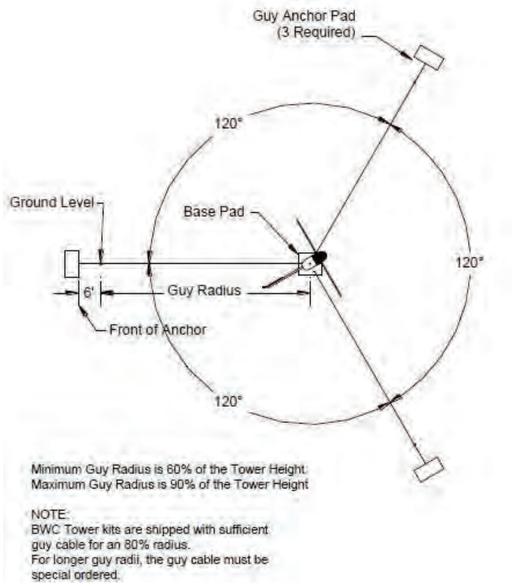
Figure 4.4.1 Wind - Diesel Hybrid System in Hateruma Island of Japan

4.4.2 Installation

The procedure for wind turbine installation depends on the type of wind turbine. In general, manufactures provide an installation manual.

(1) Tower Foundation

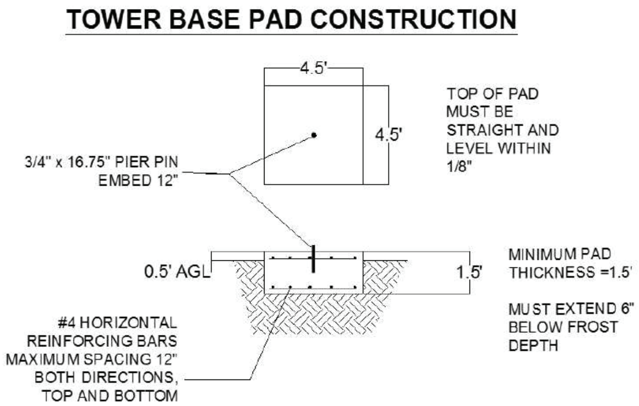
The following figure shows basic foundation layout for Guyed-Lattice Tower. This kind of tower is often used for small wind turbines. The three guy radii do not necessarilyhave to be exactly the same length, but the variation between them on the tower should be kept within +/- 8% of the tower height.



Source: Installation Manual BWC EXCEL 10

Figure 4.4.2 Layout for Guyed-Lattice Tower

The following figure shows the recommended base pad for a 10 kW wind turbine (BWC EXCEL 10). Construction of this pad requires only simple forms and reinforcement bar. The base pad hole should be excavated deep enough that approximately 6 in (approx. 15cm) of sand can be placed in the hole prior to pouring in the concrete.



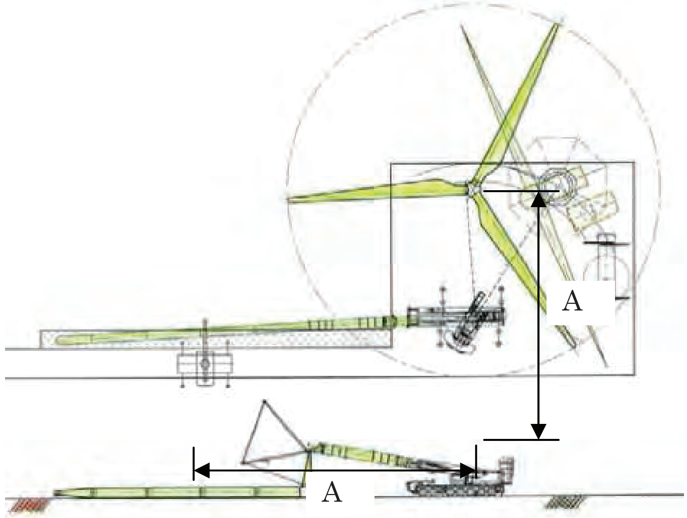
Source: Installation Manual BWC EXCEL 10

Figure 4.4.3 Foundation of Guyed-Lattice Tower

To installa Guyed-Lattice Tower, anchors should withstand the statistic and dynamic loads acting on the wind system. The holding power of the anchors depends on the area of the anchor, its depth and the soil condition. Wind system manufactures specify that their standard anchor designs are intended only for soils that are cohesive such as those with a high clay content under normal conditions. Anchor holding capacity decreases as the moisture content increases. To determine the soil’s holding capacity at the candidate site for a wind installation, soil testing with a probe is necessary. The most common method for anchoring a tower is to excavate a hole and fill it with reinforced concrete.

(2) Erection of Tower

For small wind systems, erection of the tower is not very difficult. It can be erected by a crane or gin pole. Vergnet’s towers feature a guyed, tubular mast with accompanying gin pole; and are the type which have been installed in Marsabit as shown in Figure 4.7.9. Where introduction of wind power generation is planned, the field should be assessed in terms of its natural and social conditions, to selecta site where construction is possible. In the case of installation of a single wind turbine, the field with the most suitable wind characteristics should be selected in the available area. Occupancy dimensions when a wind turbine is assembled on ground and installed are shown below.



- 500 kW Class： A=50 m×50 m
- 1,000 kW Class： A=65 m×65 m
- 2,000 kW Class： A=85 m×85 m

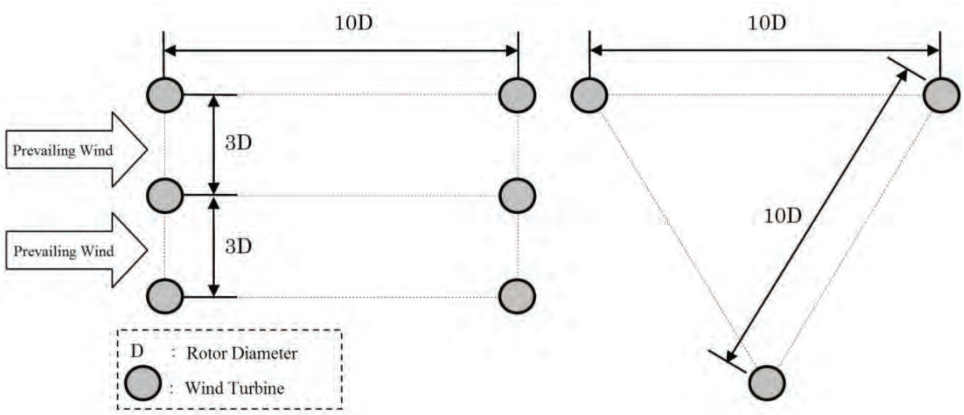
Source: Guidebook for Wind Power Introduction: NEDO

Figure 4.4.4 Occupancy Dimensions for Construction

(3) Layout of Wind Turbines

It is necessary to decide the layout with consideration of prevailing wind direction at installation site if multiple wind turbines will be installed. The obstructed area of wind characteristics formed leeward of the wind turbine is called a wake area. If a wind turbine is installed in the wake area, its power output decreases greatly. The wake area is confirmed by experimentation and actual measurement. It is approximately 3 times the rotor diameter for wind direction in the right angle, and approximately 10 times in the leeward direction. Therefore, construction spots should be avoided in these wake areas when multiple wind turbines are installed.

In areas where excellence direction of the wind appears conspicuously, layout area of the wind power generation is planned with 10D times 3D. However, in areas where excellence direction of the wind does not appear conspicuously, layout area of the wind power generation is planned with 10D times 10D. A concrete layout example is shown in the figure below.



Source: Guidebook for Wind Power Introduction: NEDO

Figure 4.4.5 Layout of Wind Turbine (Multiple Installation)

4.5 Construction Management and Inspection

4.5.1 Implementation Schedule

Adequate levelled land area for work of assemble the blades, tower construction and the main jib assembly of the truck crane is required to build the wind power generation. Because construction of foundation of the wind power generation is completed, it is necessary to conduct schedule adjustment with other work schedules. Depending on model of wind turbine, there is the construction method to attach each piece of blade to a nacelle directory without assembling a blade on ground. In addition, there is the method of construction without the large-scale crane truck using a special lifts. In this case, the land area to be prepared for construction works becomes smaller. As for installation work of switchboard and cubicle, electrical works and other works concerned, may be carried out for the same period. Therefore schedule adjustment is necessary about each works from a planning phase of the works. For conveyance and boost work of the heavy load, it is careful about loading and hoisting loads. For conveyance and boost work of the heavy materials, it is necessary to be careful about loading and hoisting loads. In addition, it is necessary to be careful about changes of wind speed during working state, specifically. The construction work in the hazardous condition is never conducted. It is necessary to take preventive measures against approaches to the construction work zone except the person concerned with work. In addition, it is necessary to pay attention about the matter written in a specification of works. As for the construction period, it takes approximately around three months for a wind turbine, from commencement of civil engineering work to the end of trial run. The work schedule is a reference term so that for the schedule varies with capacity of wind turbine and the process of installation. In the case of installation of a large-scale wind farm, for example 10 turbines of 2,000kW class, usually construction period will be required more than 12 months. However, in this case, construction period varies with construction condition greatly.

Installation of small scale wind turbine is not taking long period. However followings should be considered when preparing a schedule for installation.

- Procurement and shipping schedule of necessary equipment.
- Transportation to the Project Site
- Season for installation (avoid rain season)
- Curing period of foundation
- Installation period of tower and turbine
- Wiring of building
- Connection to diesel mini-grid
- Commissioning

The detail of the schedule has to be determined with installer.

Table 4.4.1 Implementation Schedule

N	Schdule of Wind Turbine Construction		1st Month	2nd Month	3rd Month	4th Month
	Milestone		●Groundbreaking	●Receive electricity		●Hand over
1	Civil Works	Road and Land Construction				
		Construction of Basement				
		Maintains the area of the generating plant				
2	Electrical Works	Wireing for interconnection				
		Installation of switchboard and the cubicle				
		Wiring and Grounding Works				
3	Wind Turbine (including transportation)	Assembly and Installation of Tower				
		Assembly and Installation of nacell and rotor				
		Installation and the wiring of the control unit				
4	Monitoring device	Installation of monitoring devices				
5	Comissioning Test	Examination by Manufacture (adjustment)				
		Self-imposed test				
		Testing Operation				

Prepared by JET

4.5.2 Inspection

Inspection has to be conducted by REA or MoE&P after installation of the wind turbine. The inspection points are different the types of wind turbines. In general, the points are written in the owner's manual of wind turbine. The points of inspection have to be carefully confirmed during installation works for supervising. The following list shows typical main points for inspection of wind turbine.

(1) Inspect each of the anchor points. Ensure that all hardware is secure and guy wires are properly tensioned. Check to ensure that no strands are broken and turnbuckle safety cables are in place.

(2) Inspect the blades for:

A. Cracks outboard of the hub pad, in the blade itself

B. Condition of the leading edge protection tape

C. Leading or trailing edge damage

D. Condition of the paint

E. Check the torque on the blade nuts. Recommended torque value is written in the owner's manual.

(3) Inspect the tower for:

A. Check that the tower wiring is properly secure

B. Check all fasteners

C. Look for any cracks in the tower structure

D. Check the condition of guy-wire attachment

(4) Check the grease of bearings.

(5) Inspect for cracks: main frame, tail boom and fin and other parts.

(6) Check the connection on all ground rods and hardware.

(7) Inspect the wire run, particularly all electrical connections.

4.6 Wind – Diesel Hybrid System in Kenya

There are two Diesel-Wind Hybrid Generation systems in Kenya as shown in below.

A. Habaswein Power Station	Diesel:	500 kVA
	Wind:	20 kW x 3
	PV:	30 kW
B. Marsabit Power Station	Diesel:	2000 kVA (1000 kVA x2)
	Wind:	490 kW (245 kW x 2)

In the review of existing wind power project, operational condition of Habaswein Diesel - Wind - Solar PV hybrid system was examined. And also, Wind data of Habaswein was studied.

(1) Habaswein

1) Analysis of Wind Data

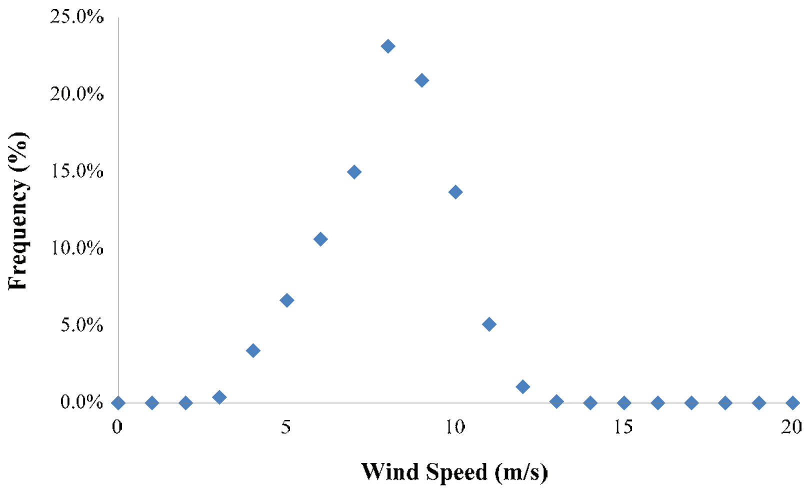
Wind speed and direction are being monitored at 20 meters above ground level in Habaswein wind monitoring site. The following figure shows frequency distribution of wind speed in August 2011. The frequency distribution of wind speed is largest at wind class 8, where wind speed is high as between 7.5m/s and 8.5m/s. Weibull distribution is a continuous probability distribution. The Weibull distribution is characterized by two parameters, one is the shape parameter k (dimension less) and the other is the scale parameter c (m/s). The shape parameter k becomes larger with the increase of average wind speed. In Japan, Weibull parameter k is recorded between 0.8 to 2.2. In Habaswein, Weibull-k is recorded high as 5.18. In general, the value of Weibull-k for the annual average is between 2.0 and 2.5 at windy sites suitable for wind power development. However, wind data are obtained only for a month at Habaswein, the number of sampling data was not enough for estimating Weibull-k.

Weibull-k : 5.18

Weibull-A: 8.6 m/s

Mean Wind Speed 7.9 m/s

Power Density: 348 W/m^2



Prepared by JET

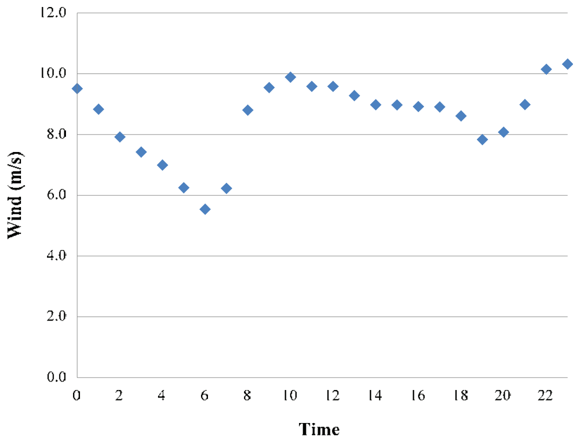
Figure 4.6.1 Frequency Distribution of Wind Speed

Table 4.6.1 Frequency Distribution of Wind Speed

Wind Class	Range of Wind Speed (m/s)	No. of Data (20m)	Frequency (%)(20m)
0	0<V<0.5	0	0.0%
1	0.5<=V<1.5	0	0.0%
2	1.5<=V<2.5	0	0.0%
3	2.5<=V<3.5	16	0.4%
4	3.5<=V<4.5	149	3.4%
5	4.5<=V<5.5	292	6.7%
6	5.5<=V<6.5	466	10.6%
7	6.5<=V<7.5	657	15.0%
8	7.5<=V<8.5	1015	23.1%
9	8.5<=V<9.5	918	20.9%
10	9.5<=V<10.5	600	13.7%
11	10.5<=V<11.5	224	5.1%
12	11.5<=V<12.5	46	1.0%
13	12.5<=V<13.5	4	0.1%
14	13.5<=V<14.5	0	0.0%
15	14.5<=V<15.5	0	0.0%
16	15.5<=V<16.5	0	0.0%
17	16.5<=V<17.5	0	0.0%
18	17.5<=V<18.5	0	0.0%
19	18.5<=V<19.5	0	0.0%
20	19.5<=V<20.5	0	0.0%
		4387	100.0%

Prepared by JET

The following Figure shows diurnal wind speed variation, where the wind speed has its peak at midnight and during daytime. Average of monitored wind speed data is high as 7.9 m/s.



Prepared by JET

Figure 4.6.2 Diurnal Wind Speed

The table below shows there is a peak of wind speed at 23:00. And also, during the day time wind speed is high as 9.9m/s at 10:00. The wind speed over 9.0m/s is recorded between 9:00 to 15:00 and between 21:00 to 0:00.

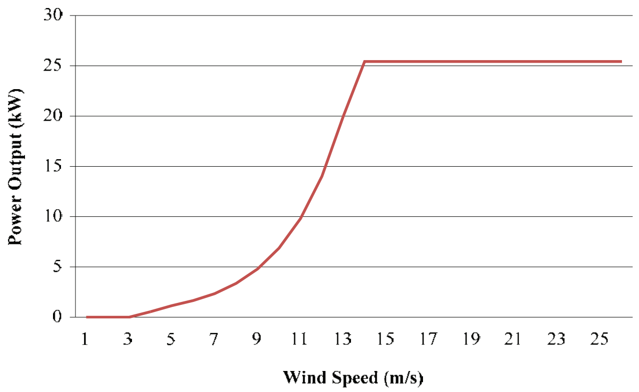
Table 4.6.2 Diurnal Wind Speed

Time	Wind (m/s)
0	9.5
1	8.8
2	7.9
3	7.4
4	7
5	6.2
6	5.5
7	6.2
8	8.8
9	9.5
10	9.9
11	9.6
12	9.6
13	9.3
14	9
15	9
16	8.9
17	8.9
18	8.6
19	7.8
20	8.1
21	9
22	10.1
23	10.3
Average	7.9

Prepared by JET

2) Estimated Power Output

The figure below shows performance curve of a wind turbine which installed Habaswein power station. Rated power output of the turbine is 20 kW.



Prepared by JET

Figure 4.6.3 Performance Curve of GE-200

On the basis of the analysis of wind power at Habaswein and performance curve of GE-200, power output is estimated as shown table below.

Table 4.6.3 Estimated Power Output

Wind (m/s)	Power Output (kW)	Wind Speed Frequency	Net kW (kW)
0	0	0	0
1	0	0	0
2	0	0	0
3	0.55	0	0
4	1.15	0.03	0.04
5	1.65	0.07	0.11
6	2.35	0.11	0.25
7	3.36	0.15	0.5
8	4.8	0.23	1.11
9	6.86	0.21	1.44
10	9.8	0.14	1.34
11	14	0.05	0.71
12	20	0.01	0.21
13	25.43	0	0.02
14	25.43	0	0
15	25.43	0	0
16	25.43	0	0
17	25.43	0	0
18	25.43	0	0
19	25.43	0	0
20	25.43	0	0

Prepared by JET

Total Net kW 5.74 W

Net kW (include loss)	4.60	kW
Rated Power Output:	20	kW
Capacity Factor	23.0%	
Estimated Daily Output	110.3	kWh/day

3) Operational Data

Following photos show main components of Diesel - Wind - PV Hybrid system at Habaswein power station. Site survey at Habaswein was carried out from 5th to 8th October 2013. At the site, operational data of hybrid generation system was gathered. The data collected at site and information were analyzed.

Wind 20kW (GE-200)

Solar PV 30kW

Diesel 500kVA

Battery Bank 5 kVA

Figure 4.6.4 Wind - PV - Diesel Hybrid System in Habaswein

Taken by JET

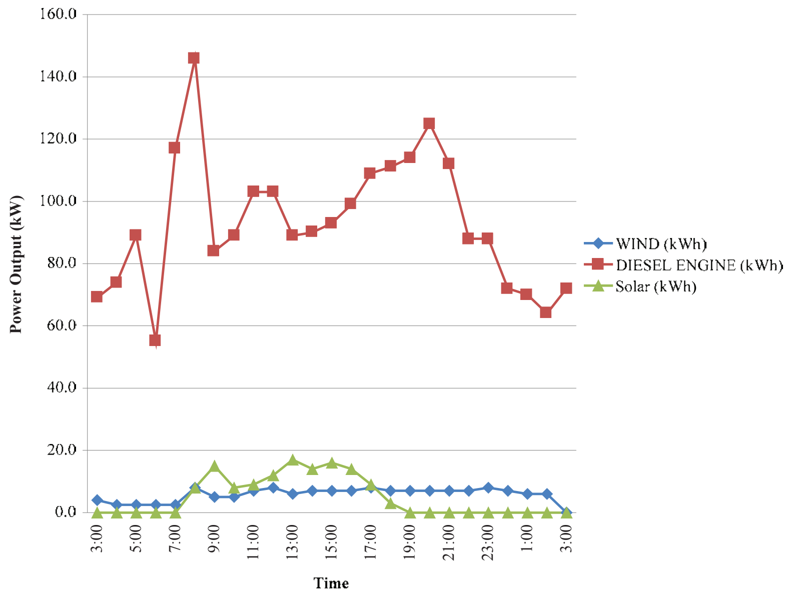


Figure 4.6.5 Operational Data of Habaswein Power Plant

Prepared by JET

Table 4.6.4 Operational Data of Habaswein Power Plant

Date	TIME	WIND (kWh)	DIESEL (kWh)	SOLAR (kWh)
2013/5/4	3:00	4.0	69	0
	4:00	2.5	74	0
	5:00	2.5	89	0
	6:00	2.5	55	0
	7:00	2.5	117	0
	8:00	8.0	146	8
	9:00	5.0	84	15
	10:00	5.0	89	8
	11:00	7.0	103	9
	12:00	8.0	103	12
	13:00	6.0	89	17
	14:00	7.0	90	14
	15:00	7.0	93	16
	16:00	7.0	99	14
	17:00	8.0	109	9
	18:00	7.0	111	3
	19:00	7.0	114	0
	20:00	7.0	125	0
	21:00	7.0	112	0
	22:00	7.0	88	0
	23:00	8.0	88	0
2013/5/5	0:00	7.0	72	0
	1:00	6.0	70	0
	2:00	6.0	64	0
Total Output	(kWh/day)	144	2,253	125

Prepared by JET

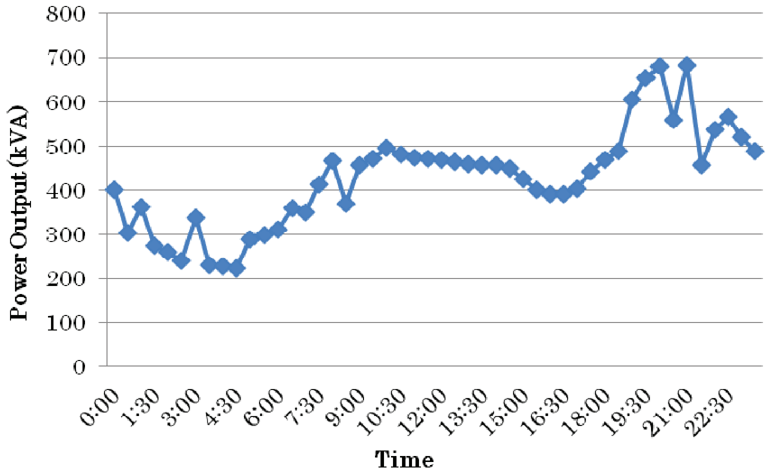
Capacity Factor:	Wind	15.0%
	Solar PV	17.4%

(2) Marsabit

Figure 4.4.6 shows power output from Marsabit diesel power station. Marsabit has a peak of power demand curve around 20:00. And the maximum power demand is between 600 to 800 kVA. There are two wind turbines interconnected to the isolated grid in Marsabit.

At the end of February 2014, the power generated by two wind turbines are not fully supplied to the grid because of the wind turbines cause fluctuation of the frequency. In Marsabit, wind penetration becomes too high to keep the frequency in stable condition during midnight to morning when power output from diesel generator is small and wind blows strong sometimes. Therefore, normally only one wind turbine is operated and the turbine is disconnected during that period.

The following pictures show wind turbines, diesel power plant, operating monitor and diesel generator in Marsabit.

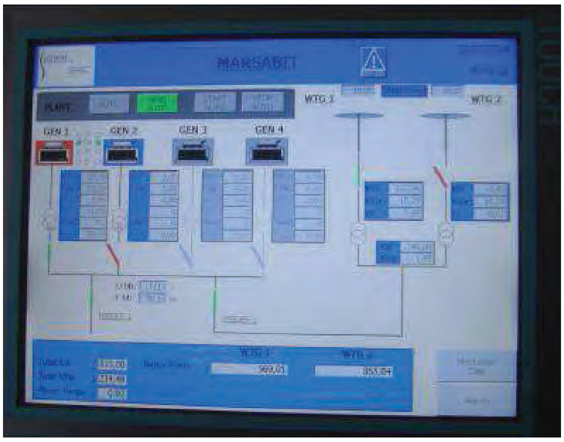


Prepared by JET

Figure 4.6.6 Operational Data of Marsabit Power Plant

Wind 245kW (GEV MP) x 2

Diesel Power Plant

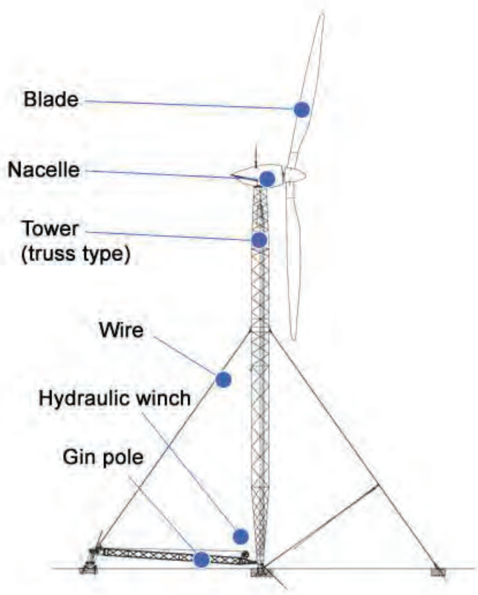

Monitoring System


Diesel Generator (1000 kVA)

Taken by JET

Figure 4.6.7 Wind- Diesel Hybrid System in Marsabit

The following figure shows the specification of wind turbine installed at Marsabit. The wind turbine is manufactured by Vergnet, a French company. The rated power output of a wind turbine is 245 kW. The wind turbine has two blades with 32 meters rotor diameter.



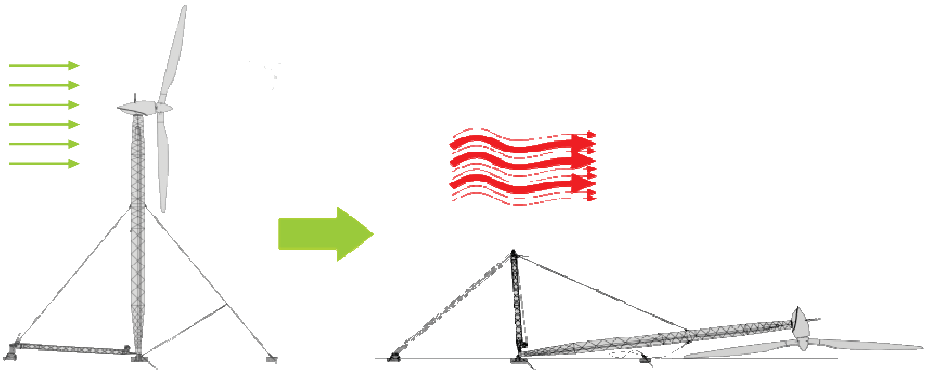
Manufacture / Country	Vergnet / France
Rated Power Output	245 kW
Rated Wind Speed	13 m/s
Cut-in / Cut-off	4 m/s / 20 m/s
Number of blades	2 (downwind type)
Rotor Diameter	32 m
Hub Height	38 m

Prepared by JET

Figure 4.6.8 Specification of Wind Turbine

Vergnet's towers feature a guyed, tubular mast with accompanying gin pole. It is easy to conduct for maintenance at site because no heavy duty vehicles are necessary. In addition, it is easy to lay the tower when strong wind such as typhoon forecasted.

The tower is prevented from moving laterally during erection by two guys at right angles to the lift. The free guy cable is routed to the top of the gin pole. The tower is raised by drawing a block and tackle together between the gin pole and the free anchor. Figure 4.6.9 shows the tower of Vergnet wind turbine.



Source: Okinawa Enetech

Figure 4.6.9 Tower of Vergnet GEV Wind Turbine

CHAPTER 5. OPERATION & MAINTENANCE

5.1 Operation and Maintenance

Maintenance and inspection are essential to maintain the high operating rate of the wind turbine. For O&M, daily monitoring of operation, periodical and irregular maintenance and the repair of equipment are required. Monitoring of operation with daily inspection contribute detection of deficiency early. Objectives of the agreement about maintenance and the repair are safety operation of wind turbines with stable condition. It is necessary to keep high operating rate of wind turbine, so that rehabilitation have to be conducted promptly after the maintenance works. Generally, the maintenance means periodic inspection. And the service means investigation and rehabilitation works on parts of failure and troubles that occurs irregularly. The agreement about these operations and maintenance should be reviewed. The costs of the O&M are important factors when selecting model to evaluate economical efficiency. In the agreement with manufacture or supplier, it is necessary to consider the high specialty of works. And also, it is recommendable to carry out negotiation to manufacturer or supplier about O&M services which are shown in Table 5.1.1.

For diesel and wind hybrid system, operation and maintenance can be conducted by operators at the diesel power station. On the other hand, for small wind power system installed at the public facilities have to be operated and maintained by staff of facilities. They have to be trained by the wind company.

Table 5.1.1 Operation and Maintenance

List	Items to be considered
Contract for monitoring of operation	1) Monitoring item, contents, issues and frequency have to be clarified. 2) Qualification and condition to become a monitor have to be clarified. 3) Duty of the monitor, working condition, monitoring area has to be clarified. 4) Monitoring methods such as remote and direct monitoring have to be decided. 5) Framework corresponding to the emergency case has to be made clear. The contents which a monitor corresponds to are made clear 6) Periodic reports for the owner: Term (week, month, year), Item, reporting method and disclosed data are confirmed
Contract for maintenance (periodical Inspection)	1) Facility for maintenance (wind turbine, electrical equipment, others), contents, period of maintenance, cost, necessity of assistance, travelling expenses and transportation are decided. 2) Condition of the work fulfilment is clarified. 3) Maintenance contractual guarantee conditions for the inspection part. 4) Confirmation of road to be accessible for equipment and service engineer. And responsibility assignment of the road is clarified 5) Dissolution and renewal condition of the contract are clarified 6) If a maintenance contractor is different from an equipment supplier, term charge out, guarantee conditions, Warranty area and a condition and a spare item are clarified. 7) Possibility of delivery of consumable supplies 8) Target term is made clear
Contract for maintenance (irregular inspection)	1) Target range of the servicing (a product, work, and conveyance), contents, time of service, cost, necessity of assistance, contents of warranties is clarified. 2) Setting of the repair term considering arrangement of the heavy machine when nonconformity occurred to large-sized equipment, transportation and procurement of parts. 3) Procedure of the service (from whom, until when, who, what) 4) Confirmation of road to be accessible for equipment and service engineer. And responsibility assignment of the road is clarified

List	Items to be considered
Contract for repair (modification, repair)	1) Modification, purpose of the repair, effect, term and costs are clarified 2) Modification, coverage for the repair result, term and substance are clarified 3) Necessity of securing of access road for heavy duty machine with the modification and repair are clarified. Responsibility assignment on the works is clarified. 4) If enforcement of modification and the repair is different from an equipment supplier, necessity such as the coverage of the equipment supplier and the modification of condition is made clear 5) If enforcement of modification and the repair is different from an equipment supplier, condition and range of disclosed information from owner company are clarified
Spare parts	1) Consumables, spare parts, replacement period and price are clarified 2) Supplement spare parts stocked by operating company, aged consumables, new model. 3) Necessity of exchange of spare parts. The defrayal of costs is made clear.
Tools and fixture	1) The scope of supply by operating company side, cost and compensation have to be clarified. 2) The scope of supply by company in charge of O&M, cost and compensation have to be clarified. 3) Necessity of special fixture, availability, cost, operation are clarified
Right of access	Monitoring operation by owner company, maintenance, right of access to wind turbine is disclosed to service company
Training	1)Training of owner company by the equipment supplier: contents, term and limitation of operation are clarified 2)Training for the engineer of the owner company for primary correspondence: contents and the defrayal of costs are clarified 3)Training of operation monitoring company by owner company: Term and limitation operation are clarified 4)The training of the maintenance company by owner company: Contents and operating range are clarified 5)Training of the service firm by owner company: Contents and operating range are made clarified
Restriction of debt	1) If supplier conducts modification or exchange of equipment without compliance of the proprietor: Responsibility and charge out of the supplier for nonconformity which accrued are clarified. 2) If proprietor modifies it without the compliance of the supplier: Responsibility and charge out of the system owner for nonconformity which accrued are clarified. 3) Dissolution of maintenance service, manifestation of reclamation contents

Prepared by JET

5.2 Periodical Inspection

The wind turbine generator has many mechanical parts, and periodical inspections such as refilling of the lubricating oil or the exchange of consumable supplies are required.

The company in charge of O&M and REA, MoE&P or owner company bind a maintenance agreement together for the purpose of improving operating rate so that mechanical and electrical inspections are carried out. The periodic inspection varies according to a manufactures but four times of inspection in a year is recommended by the manufactures in general. Therefore, REA or MoE&P can include periodic inspection in the tender document.

For inspection of contents, the visual inspection will be conducted for cable, blade and tower booms. Moreover, lubricating oil refilling, terminal strapping, bolt dip, and braking system will be inspected. It is necessary to change oil for braking valve unit, gear box and oil hydraulic brakes regularly.

Table 5.2.1 Periodical Inspection

Item	Contents of Inspection
Visual Inspection (4 times / year)	All parts are confirmed in appearance (discoloration, nasty smell, extraordinary noise, modification, fissuring)
	Inspections such as the rusting
	rain-water encroachment
	Inspection of each department fluorescent light fittings
Inspection of Oil (2 times / year)	Canned grease exchange of each bearing part
	Grease refilling of each bearing part and revolving superstructure of nacelle
	Confirmation of oil quantity in gear box of yaw control system
	At pitch gear box, oil quantity of the oil hydraulic brake unit will be confirmed
Inspection on Mechanical Parts (1 time / year)	Fastening of the tower foundation bolt, abnormality is judged from surface of the basement
	Fastening confirmation of the bolts of blades
	Clamping of the bolt except blade and the tower foundation is confirmed
	Changing oil of the yaw gear box
	Changing oil of the pitch gear box
	Changing oil of the oil hydraulic brake unit
Inspection on Electrical Parts (1 time / year)	Inspection and adjustment of each sensor switch of wind turbine
	Connection of the main circuit is confirmed
	Each parameter of the wind turbine is confirmed
	The performance test of all parts
	Test of protective system

Prepared by JET

CHAPTER 6. ECONOMIC CONSIDERATIONS

6.1 Benefit from Wind

The cost of installation of wind turbine is simply the cost of the wind turbine, tower, wiring installation and taxes and so on. Maintenance costs are expenses for servicing or repairing the wind system. According to "Wind Power", the vast amount of experience from commercial wind turbine indicates that the cost of operating and maintaining small and medium size turbine is about 1 cent per kilowatt-hour in U.S.A.

One of the advantages using wind energy over generating electricity by conventional means is the free fuel. Once wind turbines are installed, the energy produced costs little over the remaining life of wind turbines. The table below shows sample benefit from an installation of wind turbine with 15 kW. The benefit is the diesel cost which replaced by power supplied from the wind turbine.

Table 6.1.1 Benefit from Wind Turbine Installation

Generation capacity of the wind turbine	15	kW
Capacity factor (Wind)	20.0%	
Operation hour per day	24	Hours
Operation day per year	360	days
Annual power generation (Wind)	25,920	kWh/Y
Life time of the wind turbine	20	Years
OM cost of the generation system (% of the investment)	2.0%	
Diesel fuel cost per litter	105.0	kSh/litter
Fuel consumption	0.67	litter/kWh
Fuel cost per kWh	70.4	kSh/kWh

Benefit (Replaced Diesel Cost) 1,823,472 kSh/Y

* OM cost excludes replacement of battery, controller and inverter. Maintenance service from overseas is not included.

Prepared by JET

6.2 Cost of Wind Turbine Installation

Table 6.2 shows the cost of wind system. The wind turbine is estimated import from overseas country. Therefore, shipping cost, tower, controller, and other equipments are included in the cost of wind turbine. Cost for Installation works and the transportation to project site are depending on the contractor and selected project sites. The table below shows sample installation costs for the wind turbine installation.

Table 6.2.1 Costs of Wind Turbine Installation

	Unit	Unit Cost (USD)	Units	Cost(USD)	Cost (kSh)
Wind Turbine	kW	5,000	15	75,000	6,600,000
Inverter	kVA	700	15	10,500	924,000
Battery	kAh	3,600	4	14,400	1,267,200
Control House	(1/system)	2,000	1	2,000	176,000
Installation Materials	kW	600	15	9,000	792,000
Installation Work	kW	500	15	7,500	660,000
Transportation	kg	3	1,000	3,000	264,000
Total Investment Cost	-	-	-	121,400	10,683,200

Prepared by JET

6.3 Project Cost

Table 6.3 shows installation of a wind turbine at existing diesel power plant. The costs for the rehabilitation of the existing diesel power plant are not included. According to the Central Bank of Kenya the discount rate is 7% at 31st December 2010 in Kenya. In April 2014 The World Bank released its Commodity Forecast, which predicts that world crude oil price will decrease from $104/barr. in 2013 to $97/barr. by 2020. In the table, fuel price escalation rate for 20 years is estimated as 2%. The following calculation of EIRR, diesel consumption rate at Baragoi diesel power plant was applied.

Table 6.3.1 EIRR Wind Turbine Installation

Year	Benefit	Cost						Cumulatuve
	saved fuel cost (kSh)	Initial investmen	O&M	Battery	Inverter	Controller	TOTAL	Revenue
0		-10,683,200					-10,683,200	-10683200
1	1,823,472		-132,000				-132,000	1,691,472
2	1,859,941		-134,640				-134,640	1,725,301
3	1,897,140		-137,333				-137,333	1,759,807
4	1,935,083		-140,079				-140,079	1,795,004
5	1,973,785		-142,881				-142,881	1,830,904
6	2,013,260		-145,739	-1,267,200			-1,412,939	600,322
7	2,053,526		-148,653				-148,653	1,904,872
8	2,094,596		-151,627		-924,000	-330,000	-1,405,627	688,970
9	2,136,488		-154,659				-154,659	1,981,829
10	2,179,218		-157,752				-157,752	2,021,466
11	2,222,802		-160,907				-160,907	2,061,895
12	2,267,258		-164,125	-1,267,200			-1,431,325	835,933
13	2,312,603		-167,408				-167,408	2,145,195
14	2,358,855		-170,756				-170,756	2,188,099
15	2,406,033		-174,171				-174,171	2,231,861
16	2,454,153		-177,655		-924,000	-330,000	-1,431,655	1,022,499
17	2,503,236		-181,208				-181,208	2,322,029
18	2,553,301		-184,832	-1,267,200			-1,452,032	1,101,269
19	2,604,367		-188,529				-188,529	2,415,839
20	2,656,454		-192,299				-192,299	2,464,155
	44,305,574		-3,207,253	-3,801,600	-1,848,000	-660,000	-20,200,053	24,105,521

EIRR 14.5%
NPV 7,219,263

Project life 20 Years
Number of Target Households 150 HHs
Fuel Price Escalation Rate 2%
Exchange rate (as of 6 June, 2014) 102.0 Yen/US$
Discount Rate 7% (31 Dec. 2010, Central Bank)

* OM cost excludes replacement of battery, controller and inverter. Maintenance service from overseas is not included.

Prepared by JET

6.4 Isolated Small Wind vs. Solar PV System

The following table shows comparison of energy generation cost between solar PV and wind turbines which available in Kenya. In the calculation, cost for installation, O&M, replacement of equipments such as battery, controller and inverter are not included. In the table, costs of PV module and wind turbine with 20 meters tower are used for the calculation. Energy generation cost is calculated based on the capacity factor 13%for solar PV and 25% for Wind turbine. Wind turbine has a scale merit therefore energy generation cost becomes smaller with increase of the capacity. However, compare to the energy generation cost to solar PV and, unit energy generation cost for solar PV is smaller than the wind.

In these years, the price of PV module shows a tendency toward the decreasing. Furthermore, solar irradiation is stable throughout a year in Kenya and there are many companies dealing with solar PV system.

As for small isolated power generation system, solar PV has more feasibility than wind regarding to both aspects of economic and availability of O&M services.

Table 6.4.1 Comparison of small wind vs. Solar PV energy generation cost

Generation	Capacity (W)	Price (kSh)	Capacity Factor (%)	Energy Output (kWh/year)	Unit Energy Cost 20 years (kSh/kWh)
Solar PV	120	12,000	13.0%	136.7	4.39
Wind (1)*1	900	550,000	25.0%	1,971	13.95
Wind (2)*2	1800	866,750	25.0%	3,942	10.99
Wind (3)*3	3200	1,420,000	25.0%	7,008	10.13
Wind (4)*4	7500	3,075,440	25.0%	16,425	9.36

*1: Wind (1): Whisper 900W
*2: Wind (2): Skysystem 1800W
*3: Wind (3): Whisper 3200 W
*4: Wind (4): Bergey 7500W

Prepared by JET

CHAPTER 7. ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

7.1 Environmental Management System in Kenya

7.1.1 National Environment Management Authority (NEMA)

The National Environment Management Authority (NEMA) is a practical official body responsible for managing environment, reviewing "EIA Project Reports" and "EIA Study Reports" and issuing Environment Licenses for development projects in Kenya.

Under the Board and the Director General at the top of NEMA, the Authority has established six departments and one sub-department. Among those departments, the following ones have functions on EIA related activities. (Source, National Environment Management Authority Strategic Plan 2008-2012, June 2009, NEMA)

- The Director General appoints members of Environmental Impact Assessment Technical Advisory Committee (EIA-TAC) and prescribes the terms of reference and rules of procedure of the review of EIA related reports received by NEMA.

- The Compliance and Enforcement Department, identifies projects and programmes or types of projects and programmes, plans and policies for which environmental audit (EA) or environmental monitoring must be conducted under the Act and ensure EIAs and EAs are conducted.

7.1.2 Environmental Management System at County Level

(1) Decentralization and Administrative Structure Reform (Transitional Period)

Since the New Kenyan Constitution came into force in 2010, decentralization, administrative structure reforms and regulatory revisions for "Country System" in place of former "Province and District System" have started.

- As a matter of fact, NEMA issued a public notice with regard to the decentralization of its county functions on EIA as of 1st of July 2012 (See Figure 7.1.1).

As far as reforms of environmental management and EIA review procedure are concerned, the reform processes are in the transitional period as of January 2014.

- Due to the fact that the environmental management and EIA procedural reforms have not adequately come into effect in order to conform to the new constitutional dispensation especially on administrative units, the provisions of the current EMCA 1999 and EIA/EA Regulations (Amendment) 2009 are still in force until such a time that they will be reviewed. However NEMA through an administrative procedure has done away with District and Provincial offices and effectively replaced them with County offices.
- The transition period therefore means that the former systems (especially where the relevant laws are concerned) are still in operation alongside the current administrative re-alignment. Therefore, the former local systems of "Provincial Environmental Committee" as well as "District Environmental Committee" are envisaged to be reviewed.

(2) Provincial Environmental Committee (PEC) & District Environmental Committee (DEC)

According to the current EMCA 1999 and EIA/EA Regulations (Amendment) 2009, NEMA operates at provincial and district levels. Namely the Provincial Environment Committees (PECs) and District Environment Committees (DECs) are a primary mechanism for NEMA to undertake its functions, which will be reviewed to County Environment Committee in order to conform to the new administrative structure of County system.

nema

mazingira yetu | uhai wetu | wajibu wetu

NATIONAL ENVIRONMENT MANAGEMENT AUTHORITY

PUBLIC NOTICE

DECENTRALIZATION OF NEMA FUNCTIONS AND SERVICES

The National Environment Management Authority (NEMA), effective **1st July 2012** implemented a decentralization programme to counties. This is in adherence to the Constitution of Kenya 2010 provisions for government agencies to devolve their operations and functions to counties to ensure efficient provision of their services. The decentralization will in particular address processing of Environmental Impact Assessment, Environmental Audit, Noise and Excessive Vibration Control and transportation of waste (garbage and sewage) licences.

SPECIFIC CRITERIA FOR DECENTRALIZATION

A. Low impact Environmental Impact Assessment (EIA) projects

The EIA for the following low impact projects shall be submitted and processed at respective offices of the County Director of Environment:

1. Residential houses (bungalows, maisonettes, flats) in zoned area (of not more than 30 units)
2. Commercial buildings (of not more than 10 storey's) in zoned areas
3. Go-downs for storage of goods only in zoned areas
4. Community based and/or constituency development Fund (CDF) projects such as:
   i. Water projects, boreholes and water pans
   ii. Roads (small feeder roads) and bridges
   iii. Markets
   iv. Cattle dips
5. Cottage industry/jua kali sector/garages
6. Car and bus parks
7. Restaurants (excluding tourism facilities in or surrounding National parks and game reserves).
8. Expansion of existing facilities for same use especially socially uplifting projects (SUPs) such as schools and dispensaries
9. Afforestation/re-afforestation programmes
10. Sand harvesting, quarrying and brick making
11. Slaughter houses (handling not more than 15 animals a day)
12. Construction of churches and mosques
13. Timber harvesting

B. Medium and low risk Environmental Audit (EA)reports

Medium and low impact project audits will be processed at respective offices of County Directors of Environment. These include:

1. Animal feed milling
2. Apartments
3. Colleges
4. Campsites
5. Metal welding
6. Restaurants
7. Schools
8. Tea farms
9. Transport Companies
10. Timber Products
11. Warehouses
12. Stadiums

C. High impact/risk projects will be processed at NEMA headquarters

All high impact/risk projects will be processed at NEMA headquarters. These include:

1. Asbestos manufacturing /based industries
2. Battery recycling
3. Airports
4. Airports hangars
5. Base transceiver stations(BTS)
6. Cement factories
7. Chemical factories
8. Distilling and blending spirits
9. Geothermal plants
10. Hydroelectric power generation plants
11. Incinerators
12. Landfills
13. Large scale irrigated agriculture farming (exceeding 50ha)
14. Molasses plants
15. Petroleum refining
16. Paper mills
17. Vegetable oil refineries
18. Steel mills
19. Sewerage works
20. Thermal power generation
21. Tanneries
22. Tourist facilities in protected areas
23. Wood preservation

N.B. All other facilities/projects not included in the high risk category list shall be submitted and processed at the respective offices of the County Director of Environment.

D. Noise and excessive vibration control licensing

Noise and excessive vibration control licences and permits shall be issued at the county level for one off activities, where noise emitted is expected to go beyond maximum permissible noise levels. Such one off activities include: weddings and birthday parties, road shows, ceremonies, parties, religious festivals, mobile cinemas among others. The licence is valid for a maximum of seven days and costs Kshs 2,200.

Permits will be issued for the following one off activities: demolition activities, construction sites, fireworks, mines and quarries, firing ranges, specific heavy duty industry. The permit shall be valid for a period of up to three months and costs KShs 5,500.

Commercial activities, discos/ live bands/ pubs, entertainment joints, places of worship among others, shall not be licenced as they are required to sound proof their premises to keep their noise to within permissible noise levels.

E. Waste transportation licensing

Licenses to transport garbage and sewage waste shall be issued at the county level. All the other categories of waste management license applications will continue to be received at county level. These will be forwarded to NEMA Headquarters for processing.

Office contacts of respective County Directors of Environment (CDE) can be found on the NEMA website at www.nema.go.ke.

For further information, please contact:

PROF. GEOFFREY WAHUNGU
DIRECTOR GENERAL
NEMA
Popo road, off Mombasa Road
P.O. Box 67839- 00200, Nairobi, Kenya
Tel: (254 020) 6005522, 020 2101370, 0724 253398, 0735 010237
Fax (254 020) 6008997

Email: dgnema@nema.go.ke Website: www.nema.go.ke
Face book: National Environment Management Authority
Report any environmental related corruption to: anticorruption@nema.go.ke

Source, a Clip DAILY NATION, Monday July 9, 2012

Figure 7.1.1 Public Notice on Decentralization of NEMA Functions and Services

7.2 EIA Procedures and Licensing System of Kenya

7.2.1 Projects Sectors Subject to EIA

Project Sectors subject to EIA procedures in Kenya are specified in the Environmental Management and Coordination Act of 1999 (EMCA) as "Second Schedule" as shown in Table 7.2.1.

Table 7.2.1 "Second Schedule" Specified in EMCA (Project Sectors Subject to EIA)

Sector	Including	
General	An activity out of character with its surrounding any structure of a scale not in keeping with its surroundings	Major changes in land use
Urban developments	Designation of new townships Establishment of industrial estates Establishment or expansion of recreational areas	Establishment or expansion of recreational townships in mountain areas, national parks and game reserves Shopping centers and complexes
Transportation	All major roads All roads in scenic, wooded or mountainous areas and wetlands, Railway lines	Airports and airfields Oil and gas pipelines Water transport
Dams, rivers and water resources	Storage dams, barrages and piers River diversions and water transfer between catchments	Flood control schemes Drilling for the purpose of utilizing ground water resources including geothermal energy
Aerial spraying.	-	-
Mining	Quarrying and open cast extraction of Precious metal, Gemstones, Metalliferous ores, Coal, Phosphates, Limestone and dolomite	Stone and slate Aggregates, sand and gravel, Clay, Exploration for the production of petroleum in any form, Extracting alluvial gold with use of mercury
Forestry related activities	Timber harvesting Clearance of forest areas	Reforestation and afforestation
Agriculture	Large scale agriculture Use of pesticide Introduction of new crops and animals	Use of fertilizers Irrigation
Processing and manufacturing industries	Mineral processing, reduction of ores and minerals Smelting and refining of ores and minerals Foundries Brick and earth wear manufacture Cement works and lime processing Glass works Fertilizer manufacture or processing Explosive plants Oil refineries and petrochemical works Tanning and dressing of hides and skins Abattoirs and meat processing plants Chemical works and processing plants Brewing and malting Bulk grain processing plants	Fish processing plants Pulp and paper mills Food processing plants Plants for manufacture or assembly of motor vehicles Plant for the construction or repair of aircraft or railway equipment plants for the manufacture or assembly of motor vehicles plants for the manufacture of tanks, reservoirs and sheet metal containers plants for manufacture of coal briquettes plants for manufacturing batteries
Electrical infrastructure	Electrical generation stations Electrical transmission lines	Electrical sub-stations Pumped storage schemes
Management of hydrocarbons	Storage of natural gas and combustible or explosive fuels	
Waste disposal	Sites for solid waste disposal Sites for hazardous waste disposal Sewage disposal works	Works involving major atmospheric emissions Works emitting offensive odours
Natural conservation areas	Creation of national parks, game reserves and buffer zones Establishment of wilderness areas Formulation or modification of forest management policies Formulation of modification of water catchment management policies	Policies for the management of ecosystems especially by use of fire Commercial exploitation of natural fauna and flora Introduction of alien species of fauna and flora Introduction of alien species of fauna and flora into ecosystems
Nuclear Reactors	-	-
Major developments in biotechnology	Introduction and testing of genetically modified organisms	

Source: Environmental Management and Coordination Act of 1999 (EMCA)

However, "Second Schedule" does not specify the scale and size of each project. Namely without reference to scale or size of a project fall under the Second Schedule, such a project shall go through the EIA procedures.

(1) Renewable Energy Projects and necessity of EIA

Renewable Energy Projects (PV, Mini hydro, Bio-gas and Wind power systems) which falls under "No. 10 Electrical Infrastructure" in the "Second Schedule" of EMCA. Therefore, all Renewable Energy Projects are naturally subject to the EIA procedures.

(2) Draft NEMA EIA Guidelines and Administration Procedures

In addition, NEMA developed a Draft EIA Guidelines and Administration Procedures in November 2002 in response to the National Policy on Environment and EMCA 1999. The NEMA Draft EIA Guidelines provides procedural guidelines for,

- Implementation of EIA
- Monitoring and Environmental Audit (EA)
- Strategic Environmental Assessment (SEA)
- Issues of Trans-boundary, Regional and International Conventions, Treaties and Agreements
- Steps in EIA studies and Environmental Audits
- The contents and format of the study reports to be submitted to NEMA
- The EIA study review process and decision-making, and others.

CHAPTER 7 of the NEMA Draft EIA Guidelines mentions that Lead agencies are mandated by section 58 of the EMCA 1999, in consultation with the Authority to develop EIA Guidelines to ensure that environmental concerns are integrated in sector development policies, plans, projects or programmes. The sector guidelines shall focus on specific mandates in line with the statutory relationships with the administration of the EIA process.

- However, such sector guidelines have not been developed by relevant lead agencies excluding the sector of petroleum (Source, A meeting with NEMA HQ).
- In addition, the Draft Guidelines is rendered a rather conceptual guidance. Practically, the processes of EIA and the licensing shall refer to EIA/EA Regulations (Amendment) 2009.

7.2.2 EIA Review Process and Licensing

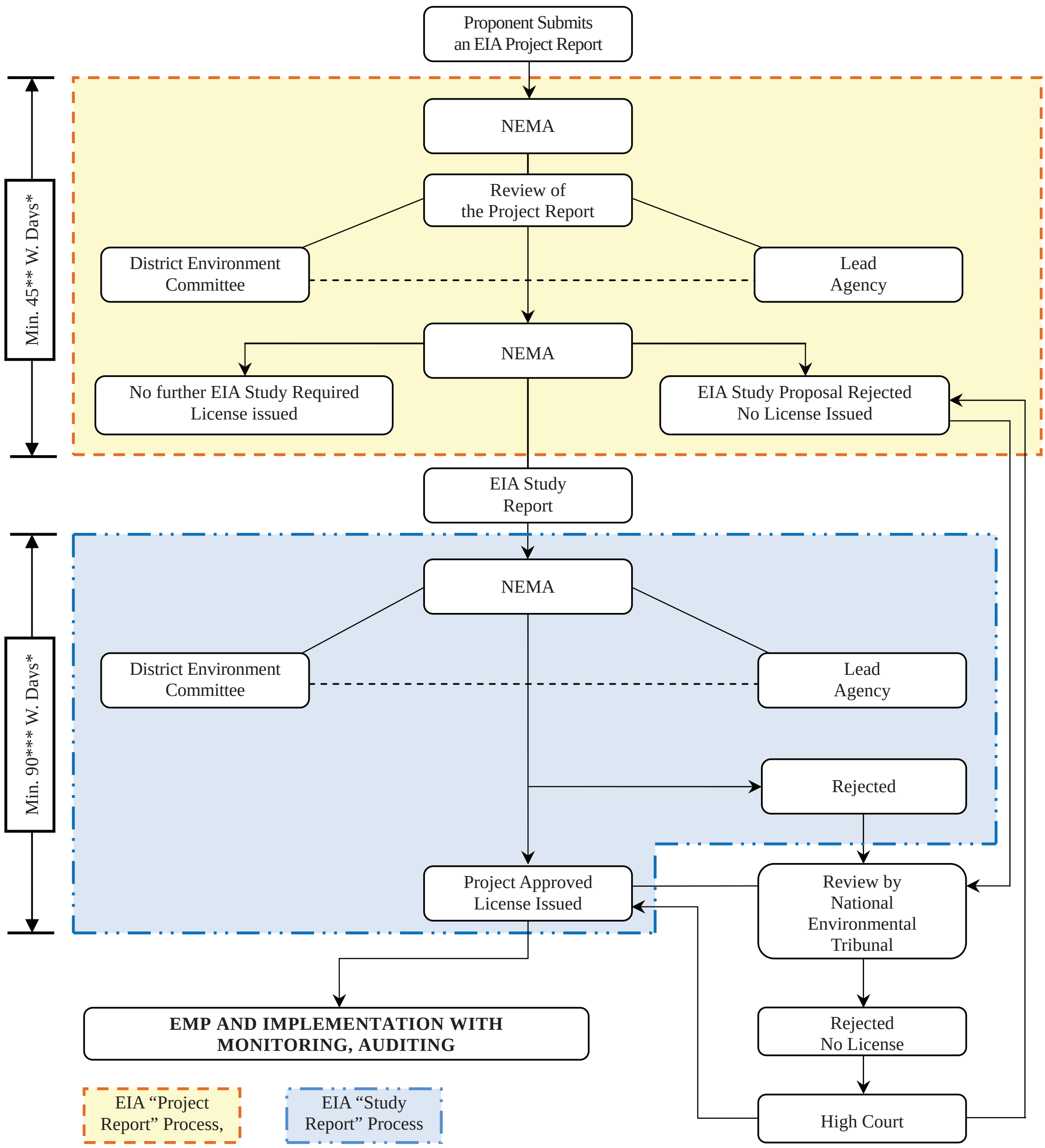
The Environmental Management and Coordination Act of 1999 (EMCA) and EIA/EA Regulations (Amendment) 2009 specify the EIA Review process which consists of the following two steps.

- EIA "Project Report" Process
- EIA "Study Report" Process

(1) Overview of the EIA Process

Based on EMCA 1999, EIA/EA Regulations (Amendment) 2009 and discussions with NEMA officials as well as considering the decentralization of NEMA's functions at the County level, Kenyan EIA entire procedures can be depicted as shown in Figure 7.2.1

Detail flows of "EIA Project Report" and "EIA Study Report will appear afterward (See Figure 7.2.2 and Figure 7.2.3).



*Note; *According to NEMA, "days" in the procedures stands for "Working days"*
*** According to NEMA, not "within forty-five days" but "Minimum forty-five days" for the EIA Project Report Review and Licensing period*
**** According to NEMA, not "within 90 days" but "Minimum 90 Working days" for the EIA Project Report Review and Licensing period*

Source, NEMA, (modified by the JICA Expert Team based on discussions with NEMA HQ officials)

Figure 7.2.1 Overview of the EIA Process

(2) EIA "Project Report"

According to EMCA 1999, EIA/EA Regulation (Amendment) 2009 and discussions with NEMA officials as well as considering the decentralization of NEMA's functions at the County level, the EIA "Project Report" Process can be summarized as follows and depicted in Figure 7.2.2.

- The process starts by a project proponent, selecting a consultant which must be licensed and registered with NEMA as a Lead Expert on EIA/EA
- An EIA "Project Report" shall be prepared by the consultant (Registered Lead Expert on EIA/EA). The following shows contents to be stated in the "Project Report".

Table 7.2.2 Contents of the Project Report

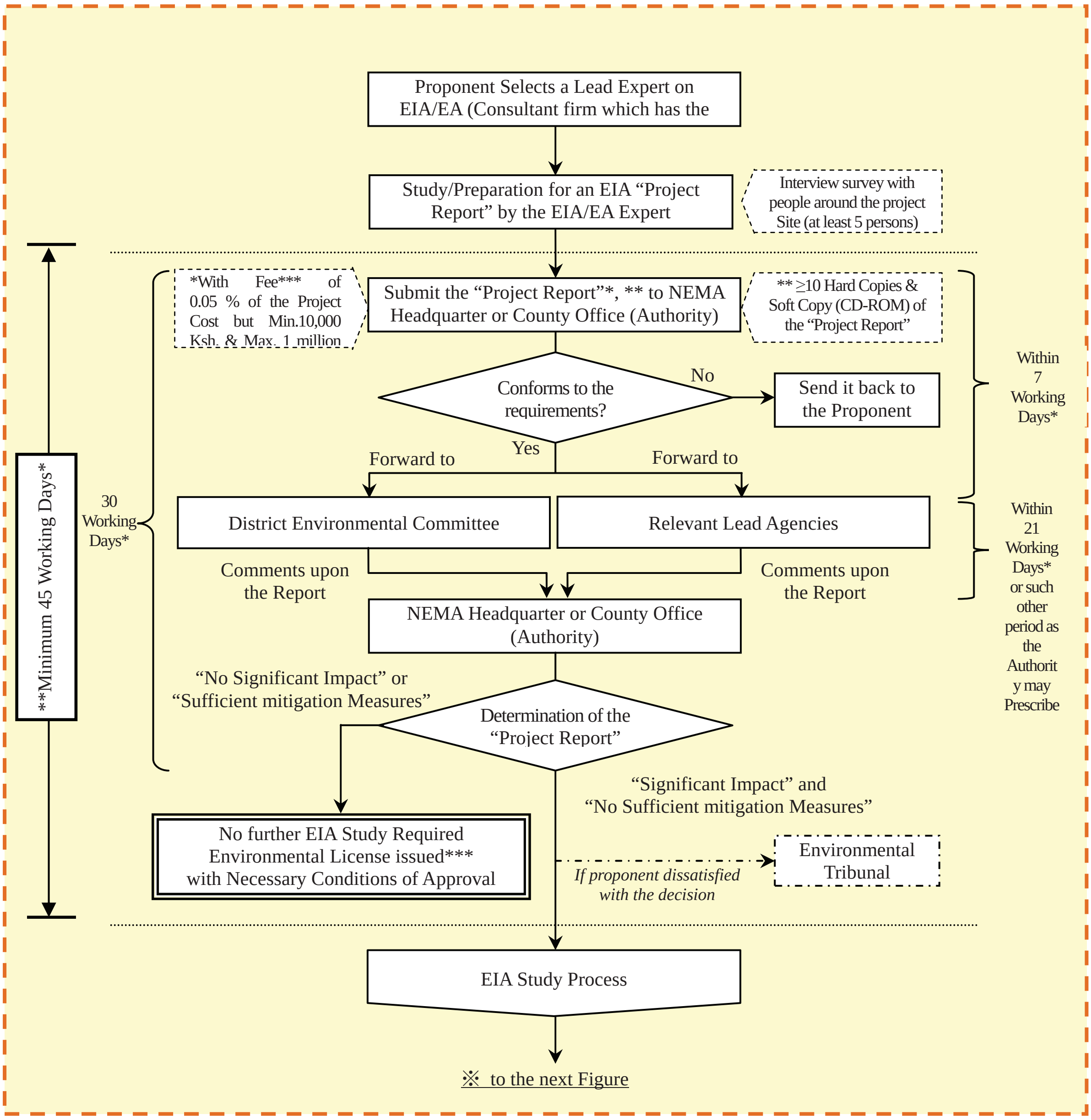
Nature of the project Location of the project including the physical area that may be affected by the project's activities Activities that shall be undertaken during the project construction, operation and decommissioning phases Design of the project Materials to be used, products and by-products, including waste to be generated by the project and the methods of their disposal Potential environmental impacts of the project and the mitigation measures to be taken during and after	implementation of the project Action plan for the prevention and management of possible accidents during the project cycle Plan to ensure the health and safety of the workers and neighbouring communities Economic and socio-cultural impacts to the local community and the nation in general Project budget Any other information the Authority may require

Prepared by JET

- The proponent shall submit at least ten copies and one soft copy (CD-ROM) of the EIA "Project Report" to the Authority (NEMA HQ or its County Office(s)) accompanied by the prescribed fees of 0.05% of the project cost. (50% of the 0.05 of the project cost paid at the time of submission of the EIA "Project Report" and the remainder of 50% paid at the time of collection of license)
- The Authority shall **within seven (7) days** upon receipt of the project report, where the "Project Report" conforms to the requirements of regulation, distribute a copy of the "Project Report" to Relevant Lead Agencies and Relevant District Environment Committee(s) (DEC(s)) for their review and written comments.
- Those comments of Lead Agencies and DECs shall be submitted to the Authority **within twenty one (21) days** from the date of receipt of the "Project Report" from the Authority, or such other period as the Authority may prescribe.
- On receipt of the comments or where no comments have been received **by the end of the period of thirty (30) days** from the date of receipt of the "Project Report", the Authority shall proceed to determine the project report.
- On determination of the "Project Report", the decision of the Authority, together with the reasons thereof, shall be communicated to the proponent **within forty-five (45) days**[1] of the submission of the "Project Report".
- Where the Authority is satisfied that the project will have no significant impact on the environment, or that the project report discloses sufficient mitigation measures, the Authority may issue a license

1 According to NEMA, not "within forty-five days" but "Minimum forty-five days" for the EIA Project Report Review and Licensing period

- If the Authority finds that the project will have a significant impact on the environment, and the project report discloses no sufficient mitigation measures, the Authority shall require that the proponent undertake an EIA study.
- A proponent, who is dissatisfied with the Authority's decision that an environmental impact assessment study is required, may **within fourteen (14) days** of the Authority's decision appeal against the decision to the Tribunal.



*Note: *According to NEMA, "days" in the procedures stands for "Working days"*
*** According to NEMA, not "within forty-five days" but "Minimum forty-five days" for the EIA Project Report Review and Licensing period*
*** 50% of the 0.05 of the project cost paid at the time of submission of the EIA Project Report and the remainder of 50% paid at the time of collection of license

Source, Prepared by the JICA Expert Team referring to the EIA/EA Regulations (Amendment) 2009 and based on discussions with NEMA HQ

Figure 7.2.2 EIA Project Report Review Process and Duration

(3) EIA "Study Report"

According to EMCA 1999, EIA/EA Regulation (Amendment) 2009 and discussions with NEMA officials as well as considering the decentralization of NEMA's functions at the County level, the EIA "Study Report" Process can be summarized as follows and depicted in Figure 7.2.3.

- An EIA study shall be conducted in accordance with a TOR (Terms of Reference) to be developed during the "Scoping" exercise, Then the TOR shall be submitted to be approved **within seven (7) days** by the Authority, Every EIA study shall be carried out by an EIA/EA Lead Expert
- During the process of conducting an EIA study, the proponent shall in consultation with the Authority, seek the views of persons who may be affected by the project.
- Namely, holding at least three public meetings with the affected parties and communities to explain the project and its effects, and to receive their oral or written comment
- A proponent shall submit to the Authority, an environmental contents of EIA "Study Report" incorporating but not limited to the following information:

Table 7.2.3 Contents of the Study Report

Proposed location of the project Concise description of the national environmental legislative and regulatory framework, baseline information, Any other relevant information related to the project, the objectives of the project Technology, procedures and processes to be used, in the implementation of the project Materials to be used in the construction and implementation of the project Products, by-products and waste generated project Description of the potentially affected environment Environmental effects of the project including the social and cultural effects and the direct, indirect, cumulative, irreversible, short term and long-term effects anticipated Alternative technologies and processes available and reasons for preferring the chosen technology and processes Analysis of alternatives including project site, design and technologies and reasons for preferring the	proposed site, design and technologies Environmental management plan proposing the measures for eliminating, minimizing or mitigating adverse impacts on the environment, including the cost, time frame and responsibility to implement the measures, Provision of an action plan for the prevention and management of foreseeable accidents and hazardous activities in the cause of carrying out activities or major industrial and other development projects, Measures to prevent health hazards and to ensure security in the working environment for the employees and for the management of emergencies Identification of gaps in knowledge and uncertainties which were encountered in compiling the information Economic and social analysis of the project Indication of whether the environment of any other state is likely to be affected and the available alternatives and mitigating measures Such other matters as the Authority may require

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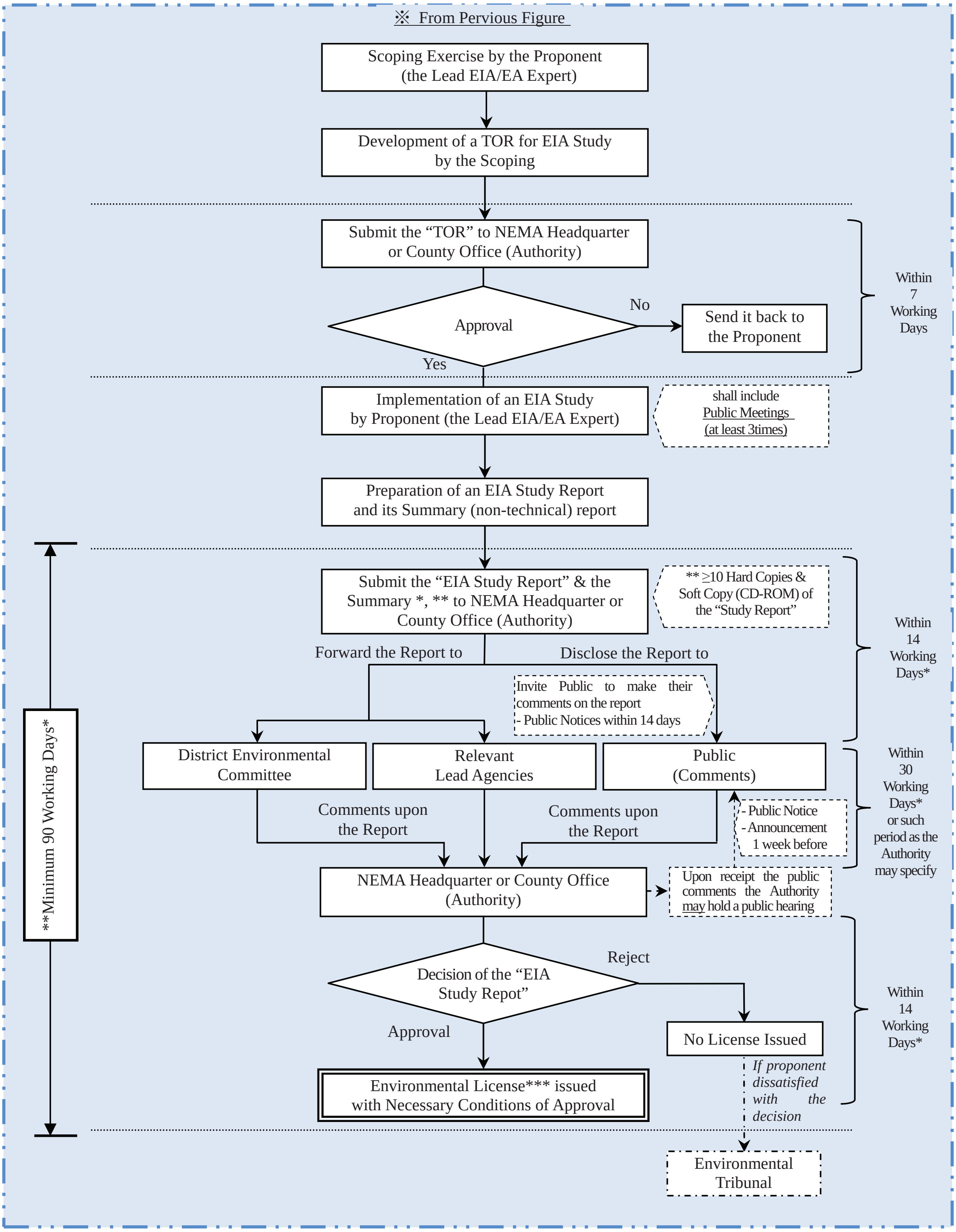
- EIA "Study Report" shall be accompanied by a non-technical summary outlining the key findings, conclusions and recommendations of the study, Proponent shall submit ten copies and a soft copy (CD-ROM) of an EIA "Study Report" to the Authority
- The Authority shall **within fourteen (14) days** of the receipt of the EIA "Study Report" submit a copy of the report to any Relevant Lead agencies as well as District Environmental Committee(s) (DEC(s)) for their comments.
- Upon receiving the EIA "Study Report", the lead agencies and DEC(s) shall review the report and shall thereafter send their comments on the "Study Report" to the Authority **within thirty (30) days** or such extended period as the Authority may specify.

- The Authority shall **within fourteen (14) days** of receiving the EIA “Study Report”, invite the public to make oral or written comments on the report, at the expense of the proponent.
- Upon receipt of these comments, the Authority may hold a public hearing
- The Authority shall give its decision on EIA “Study Report” **within three (3) months** of receiving an EIA “Study Report”
- Where the Authority approves an EIA “Study Report” , it shall issue an EIA license on terms and conditions as it may deem necessary
- A person who is aggrieved by the decision may appeal to the Tribunal against the decision.



Note: *According to NEMA, "days" in the procedures stands for "Working days"
** According to NEMA, not "within 90 days" but "Minimum 90 Working days" for the EIA Project Report Review and Licensing period
*** 50% of the 0.05 of the project cost paid at the time of submission of the EIA Project Report and the remainder of 50% paid at the time of collection of license

Source, Prepared by the JICA Expert Team referring to the EIA/EA Regulations (Amendment) 2009 and based on discussions with NEMA

Figure 7.2.3 EIA Study Report Review Process and Duration

(4) Public Comments and Public Hearing in the EIA Study Report Process

Table 7.2.4 shows differences between "Public Comments" and "Public Hearing" in the course of the EIA Study Report Process. Both public comments and public hearing are means of public consultation.

Table 7.2.4 Public Comments and Public Hearing in EIA Study Report Process

Public Comments	Public Hearing
· Invitation is done both at the time of conducting EIA and after submission of Study report	· Conducted only after submission of the EIA study report at NEMA offices
· Invitation of public comments must be done as follows · At least three public meetings for comments must be done by the EIA consultant in the course of the study · One public comments window after submission of EIA study report at NEMA office	· Public hearing done only once after submission of EIA study report
· Comments are received both by EIA consultant and NEMA	· Sessions for public hearing only organized by NEMA and the report of the public hearing only prepared by the presiding NEMA official
· Invitation for public comments is mandatory as per the regulations	· Conducting public hearing sessions is at the discretion of NEMA based on the nature of the proposed study and adequacy of the study report

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(5) Possible Schedule of EIA Review Process and Licensing for Renewable Energy Projects

In accordance with EIA processes noted above, a possible schedule of EIA reviews and licensing for renewable energy projects can be depicted as a bar-chart shown in Figure 7.2.4.

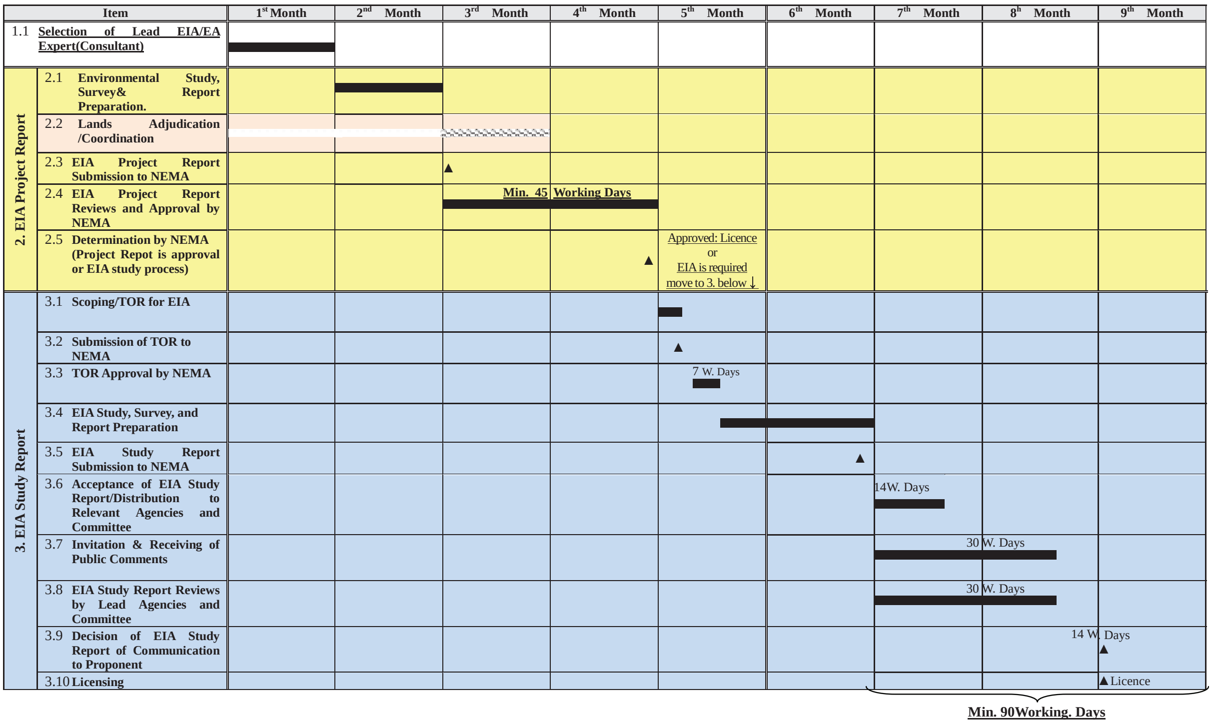

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Figure 7.2.4 Possible Schedule for EIA/Environmental Licenses

7.3 Specific Subject (Solid Waste Management)

Solid waste management issues shall be addressed in compliance with the following laws and regulations in Kenya.

- Environmental Management and Coordination Act of 1999 (EMCA)
- Environmental Management and Coordination (Waste Management) Regulations 2006
- Guidelines for E-Waste Management in Kenya 2010
- Others (if any)

7.3.1 Construction Stage

All trash and packaging materials which might result from the construction process will be collected by the contractor(s) for adequate disposal, which shall be one of the prerequisites for the contract(s) for the contractor(s) to be employed. In this regard, the solid waste management during construction stage can be secured as follow.

- REA is required to instruct contractor(s) to ensure such solid waste management.

7.3.2 Operation Stage

Replacement of used batteries, fluorescent tubes and other electrical appliances shall be managed by each project facility. REA is required to have discussions with each facility, and/or initiate stakeholder meetings in each site to discuss and find solutions for management of such solid waste as follows.

(1) E-waste

The issues of “e-waste management” are prominent. Especially e-waste components like used batteries, used fluorescent lamps and other used electrical appliances including solar PV panels, inverters, etc. are the core issues as summarized in Table 7.3.1.

Table 7.3.1 E-waste Components in Renewable Energy Projects

E-waste	Hazardous Element
Used Lead-acid batteries	Lead and Sulfuric Acid
Used Fluorescent tubes	Mercury
Used PV panels, Inverters and Other appliances	Other Heavy Metals

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(2) Hazardous and Non-Hazardous Elements

Hazardous elements and Non-Hazardous Elements in Table 7.3.1 are regulated by EMCA, especially by the Guidelines for E-Waste Management in Kenya (See Table 7.3.2 and Table 7.3.3).

Table 7.3.2 Hazardous Elements in Electrical and Electronic Equipment

Element	For example found in electrical and electronic equipment such as:
Americium	Smoke alarms (radioactive source)
Mercury	Fluorescent tubes (numerous applications); tilt switches (pinball games, mechanical doorbells, thermostats)
Sulfur	Lead-acid batteries
PCBs	Prior to ban, almost all 1930s-1970s equipment, including capacitors, transformers, wiring insulation, paints, inks and flexible sealants used PCBs.
Cadmium	Light-sensitive resistors, corrosion-resistant alloys for marine and aviation environments and nickel-cadmium batteries.
Lead	Old solder, CRT monitor glass, lead-acid batteries and formulations of PVC.
Beryllium oxide	Filler in some thermal interface materials such as thermal grease used on heat sinks of CPUs and power transistors, magnetrons, X-ray-transparent ceramic windows, heat transfer fins in vacuum tubes, and gas lasers.
Polyvinyl chloride	PVC contains additional chemicals to change the chemical consistency of the product. Some of these additives can leach out of vinyl products e.g. plasticizers that are added to make PVC flexible.

Source: Guidelines for E-Waste Management in Kenya, December 2010, National Environmental Management Authority

Table 7.3.3 Non - hazardous Elements in Electrical and Electronic Equipment

Element	For example found in electrical and electronic equipment such as:
Tin	Solder, coatings on component leads.
Copper	Copper wire, printed circuit board tracks, component leads.
Aluminium	Nearly all electronic goods using more than a few watts of power, including electrolytic capacitors
Iron	Steel chassis, cases, and fixings.
Germanium	1950s-1960s transistorized electronics (bipolar junction transistors).
Silicon	Glass, transistor, ICs, printed circuit boards.
Nickel	Nickel-cadmium batteries.
Lithium	Lithium-ion batteries.
Zinc	Plating for steel parts.
Gold	Connector plating, primarily in computer equipment.

Source: Guidelines for E-Waste Management in Kenya, December 2010, National Environmental Management Authority

Possibility of “hazard to health and environment” caused by the hazardous elements shown in Table 7.3.2, which is one of the reasons for the necessity of e-waste management.

(3) Handling Procedure of E-waste

Not like domestic waste which is generated daily, e-waste is generated after life span of each component of the project facilities has finished.

Namely, the life span of batteries and fluorescent lamps are up to about two years and that of electrical appliances including solar PV panels, inverters, etc. are up to 10-25 years. Their disposals shall be handled as summarized in Table 7.3.4.

Table 7.3.4 Handling Procedure of E-waste

Component	Possible Life Span*(years)	Handling	Remarks
Battery	3 to 8	· In order to prevent diffusion of toxic substances in batteries, used ones shall safely be kept without damage (Do not Crash! Do not Take Apart!) until properly disposed. · Used batteries can be sold to licensed e-waste handlers and/or battery producing companies in Kenya	· Licensed e-waste handlers (See Table 7.3.5) or contact each NEMA county office to get updated information on such handlers · Battery Producing Companies (See Figure 7.3.1 or contact each NEMA county office) · Purchase Prices are subject to the market trends
Fluorescent Lamp	2 to 4	· In order to prevent diffusion of mercury in fluorescent lamps, used ones shall safely be kept without damage (Do not Crash! Do not Take Apart!) until properly disposed. · Used Fluorescent Lamps shall be transported to licensed e-waste handlers in Kenya to be disposed.	· Licensed e-waste handlers (See Table 7.3.5) or contact each NEMA county office to get updated information on such handlers
LED Lamp	5	· Used LED Lamps shall be transported to registered e-waste handlers in Kenya to be disposed.	
Solar PV Panel	20 to 25	· Used Solar PV Panels shall be transported to registered e-waste handlers in Kenya to be disposed.	
Inverter	5 to 10	· Used Inverter shall be transported to licensed e-waste handlers in Kenya to be disposed.	

* Note: Vary depending on the intended use as well as status of use

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Taken by JET

A battery manufacturer already has a program to buy used batteries at KSh. 40 per kilogram

Figure 7.3.1 Used Battery Purchasing by a Battery Manufacturer

Table 7.3.5 Licensed E-waste Handlers in Kenya (As of August 2013)

Handler	Contact	District	Waste Type
EAST AFRICA COMPUTER RECYCLERS LTD	P.O .BOX 49266-00100, NAIROBI Email: eastafricancomputer@yahoo.com 07215036515 0729308221	MOMBASA	ELECTRONIC RECYCLING
WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT CENTER	P.O .BOX 48584-00100 NAIROBI Email: info@weecenter.com 0733-986-558 202060921	NAIROBI	ELECTRONIC RECYCLING

Source: NEMA (tabulated by JET)

(4) E-waste Management Structure

Used batteries, fluorescent tubes and other used electrical apparatuses/devices can be handled by organizing an e-waste management sub-committee under the Pilot Project management structure to be set up by each community and/or facility as follows:

a. The structure (sub-committee) to be organized for the e-waste management shall be discussed among stakeholders on the initiative of REA
b. Each community is to be enlightened that even the electrical apparatuses/devices such as PV panels and inverters which have a longer lifespan eventually need replacement
c. Each community is to be enlightened that those hazardous elements shown in Table 7.3.2 are hazardous to health and environment, and some hazardous substances like “lead” in batteries and some non-hazardous elements shown in Table 7.3.3 can be recycled and reused.

(5) E-waste Disposal System

Practically, the aforementioned e-wastes shall be transported to the licensed E-waste Handlers and/or battery manufacturers, in the following approach:

a. Request suppliers to take away used ones from each facility when carrying out replacements (this shall be set as a condition for carrying out replacements).

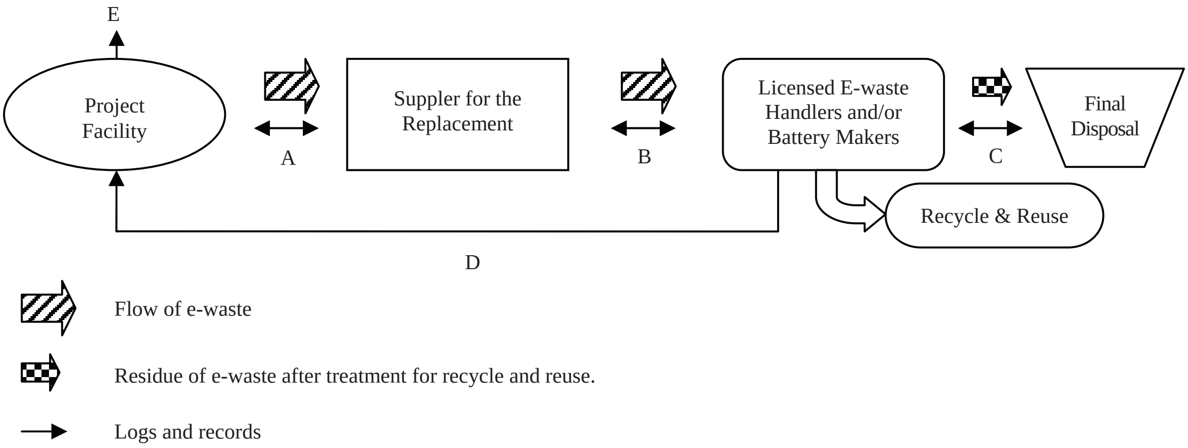
b. Being public property of the project, earnings from the sale of used e-waste including batteries shall be remitted using the "M-Pesa" system by suppliers receiving earnings from the licensed E-waste Handlers and/or battery manufacturers.

c. The earnings shall be kept in each facility as revenue.

d. In order to ensure proper transportation and treatment, an e-waste manifest system shall be introduced in the e-waste disposal system as shown in Figure 7.3.2 and Table 7.3.6.

* Manifest system: A system to keep all logs from e-waste discharge stage to transportation as well as final treatment in order to prevent illegal dispose of e-waste during the transportation as well as to make sure appropriate final treatment of such waste.

** The following web site of USEPA on Hazardous Waste Manifest System can be referred as reference.
http://www.epa.gov/waste/hazard/transportation/manifest/index.htm



A	Keep two logs on e-waste between Generator (facility) and Suppler which will transport e-waste to the (2 logs: one is for the generator and one is for the suppler)
B	Keep two logs on the e-waste between the Suppler and Licensed e-waste handler and/or Battery Maker for the treatment of the e-waste (2 logs: one is for the suppler and one is for the Licensed E-waste Handlers and/or Battery Makers)
C	Keep two logs on the reside of the e-waste between the Licensed e-waste handler and/or Battery Maker and a final disposal site (2 logs: one is for the Licensed e-waste handler and/or Battery Maker and one is for the final disposal facility like a landfill)
D	Send two copies of the logs of B and C to Generator (project facility) by which each project facility can identify the proper transportation, treatment and final disposal of the e-wastes by mail.
E	After receiving the copies in D, each facility shall report showing one of the copies to REA, as well as regulatory agency such as Ministry of Education (for Primary Schools) or Ministry of Health (for Dispensaries).

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Figure 7.3.2 Conceptual Diagram of E-waste Manifest system

Table 7.3.6 Draft E-waste Manifest Log Form

	Date:		No. of Manifest	
1	Facility (Generator)	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	E-waste	name 1:	Quantity	mode of packing
		name 2:	Quantity	mode of packing
		name 3:	Quantity	mode of packing
		name 4:	Quantity	mode of packing
		name 5:	Quantity	mode of packing
2	Suppler (Transportation)	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	Received the above listed e-waste from the Facility on date and Sign			
3	Licensed E-waste Handler and/or Battery Maker	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	Received the above listed e-waste from the Suppler on date and Sign			
	Treated appropriately the e-waste on date and Sign in compliance with the relevant laws and regulations in Kenya, especially the followings ✓ Environmental Management and Coordination Act of 1999 (EMCA) ✓ Environmental Management and Coordination (Waste Management) Regulations 2006 ✓ Guidelines for E-Waste Management in Kenya 2010			
4	Final Disposal	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	Received the residues of above listed e-waste from the Licensed E-waste Handler and/or Battery Maker on date and Sign			
	Disposed the residues on date and Sign n compliance with the relevant laws and regulations in Kenya, especially the followings ✓ Environmental Management and Coordination Act of 1999 (EMCA) ✓ Environmental Management and Coordination (Waste Management) Regulations 2006 ✓ Guidelines for E-Waste Management in Kenya 2010			

Note: At least eight copies are necessary

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7.4 Individual Subjects

While wind turbines themselves have comparatively low footprints of a couple of square meters each, they still require the consent of the landowner. A main concern with respect to environmental impacts would be noise. Due to the strict noise emission requirements in the relatively densely populated European market, wind turbines are designed with emphasis on low noise emission. At 7 m/s wind speed and standard rpm rotor speed, a turbine emits a sound level of approx. 98 dB(A), at a measurement accuracy of +/- 2 dB. At a distance of 200metres, the noise level is 45 dB(A). At lower wind speeds the noise emission is reduced and at higher wind speeds, the increasing ambient noise level from the wind masks the noise emission. Worldwide, 45 dB(A) is becoming the accepted noise tolerance level at private residences.

(1) Other Environmental Considerations

The aesthetic impact of a wind turbine is of course an individual matter and is difficult to quantify. In general, wind turbines are designed with several features to minimize visual impact to observers. The entire wind turbine, including the rotor, is coated with a discreet white/light grey finish with an anti-reflection coating for elimination of strobe effects from the sun. At times avian mortality has been a concern in relation to wind farms. Research has documented that a wind turbine with a relatively slow spinning rotor and utilizing a tubular tower with no features for perching poses no greater threat to birds than a power pole, antenna tower, or any other type of tall structure. Larger wind energy investment would require an EIA.

Care has to be taken to avoid negative environmental impacts during construction and installation. When delivering wind generators to the installation site, a large quantity of material must be transported, including concrete, steel for platforms, towers, blades, nacelles, and others. Careful packaging is required to protect the machinery during transportation and handling. This generates a pile of discarded packaging, boxes, plastic bags, Styrofoam and various other materials. After installation there will be additional garbage such as containers, used tools, pieces of metal, cables, etc. and provision have to be made to dispose of all these materials in an orderly way.

Large scale wind energy use with significant contribution towards diesel savings requires the use of large quantities of batteries. These batteries will most probably be lead acid batteries which need proper disposal and recycling of the lead and the acid that is contained in the batteries. Another potential environmental problem associated with large scale battery use is the production of H_2. Accumulation of hydrogen in battery houses can cause explosions.

Wind condition is heavily dependent on surrounding terrain and circumstances. It is therefore necessary to study the local climatic features. Wind energy development should be located so as to optimize the aesthetic qualities of the surrounding landscape and those of the wind energy development itself.

(2) Consideration of Natural and Social Conditions

It is necessary to consider the wind characteristics of the surrounding areas of the installation site to achieve maximum effect from the introduction of wind power generation. As for the location of the wind power turbines and power plant, these can be in mountain ranges, plains, coastal areas and sometimes parks or urban districts, and so on. In addition, it is necessary to consider other natural conditions that may damage the facilities and structures such as, lightning or damage from salt water. It is also necessary to consider the condition of the access road for bringing in materials or heavy machines during construction and the availability of potable water and electric power supply that will be needed during construction. In addition, compliance to local regulations, securing official licenses and permits to comply with land use policies (prohibited area; timber, farm land, urban district, park), is required. It is necessary to examine the environmental impacts such as noise, vibration, electromagnetic interference, landscape and the impact to the local ecosystem. In the technical aspect, considerations for meteorological conditions (i.e. hurricane, turbulent flow and lightning) of the site where installation is planned are important. During these past few years, there were few cases of problems with regards to landscape and ecosystem issues (the bird strike of particularly rare raptors). Therefore, consideration must be given to the concerns of local inhabitants and organizations. The summarized installation requirements that should be considered in the installation of the wind turbines are shown in Table 7.4.1

Table 7.4.1 Requirements for Natural & Social Conditions

	Items	Issues to consider
Natural Condition	Wind Condition (Speed /direction)	A site where the annual average wind speed exceeds 5 to 6 m/s at 30 meters above ground level is suitable for wind power projects.
	Wind Flow	It is necessary to conduct additional studies at sites where turbulent flow caused by complex terrain is strong. For the installation of several wind turbines, it is necessary to consider the wake effects of wind and interference between the wind turbines caused by their placement.
	Lightning	Lightning produces a large energy surge during discharge. It is necessary to consider suitable countermeasures at areas with frequent lightning occurrence.
	Damage from salt water	It is necessary to take measures for mitigation of damage from salt water on structures near in coastal areas.
	Dust (Blowing sand)	It is necessary to be take measures to mitigate damage from dust or wind-blown sand in coastal areas.
	Geology, Slope	It is necessary to consider the ground gradient and other topographic features.
Social Condition	Prohibited territory	It is necessary to consider prohibited territories, such as natural parks and the nature conservation areas.
	Land use	It is necessary to consider the current land-use policy at candidate site
	Transmission / Distribution line, Transformer	It is necessary to consider the location of transmission lines, distribution lines and transformers.
	Road, Bridge, Port	It is necessary to consider the road conditions, such as road width and curvature for transportation of materials, wind turbines and equipment. It is necessary to pay special attention to the material (space and weight) restrictions of the bridge and the harbour.
	Noise	It is necessary to pay attention to the distance from the nearest households.
	Electromagnetic radiation	It is necessary to pay attention to the distance and direction to important radio aids so as to minimize interference.
	Bio-ecology	It is necessary to consider the effect on animals and plants in nature.
	Landscape	It is necessary to pay attention on its influence on the landscape.

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CHAPTER 8. PROCUREMENT

8.1 Procurement

The procurement needs to be conducted according to Public Procurement and Disposal Act 2005 and the Public Procurement and Disposal Regulations 2006 stipulated by the Government of Kenya.

Wind projects have the components of civil works, electrical and mechanical works, and goods. It is necessary to combine applicable descriptions in the tender document.

The procurement method consists of the following:

(1) International open tender

International open tender is applied mainly when there is no or few domestic suppliers who have the experiences of similar project, and the tender calls international suppliers. There is no maximum level of expenditure.

(2) National open tender

National open tender is mainly among national suppliers. When several national suppliers have experiences of similar projects and they have sufficient abilities, this method will be taken.

(3) Restricted tender method

Restricted tender method is the procurement method that relies on the establishment of a list of authorized bidders who will be offered the opportunity to bid for a specific procurement package. The establishment of the list is subject to conditions.

Table 8.1.1 Type of Procurement and Maximum and Minimum Budget

<table>
<tr><th>Type</th><th>Goods</th><th>Works</th><th>Services</th></tr>
<tr><td rowspan="2">International
Open Tender</td><td colspan="3">Maximum is the budget allocation</td></tr>
<tr><td colspan="3">No Minimum</td></tr>
<tr><td rowspan="2">National Open Tender
(Threshold Class A)</td><td colspan="3">Maximum is the budget allocation</td></tr>
<tr><td colspan="2">Minimum is
Kshs. 6,000,000</td><td>Minimum is
Kshs. 3,000,000</td></tr>
<tr><td rowspan="2">National Open Tender
(Threshold Class B)</td><td colspan="3">Maximum is the budget allocation</td></tr>
<tr><td colspan="2">Minimum is
Kshs. 4,000,000</td><td>Minimum is
Kshs. 2,000,000</td></tr>
<tr><td>National Open Tender
(Threshold Class C)</td><td colspan="2">Minimum is
Kshs. 3,000,000</td><td>Minimum is
Kshs. 1,000,000</td></tr>
<tr><td colspan="3">Class A, B, C is the classification made by procurering entities.</td><td></td></tr>
</table>

Source: Prepared from PUBLIC PROCUREMENT AND DISPOSAL GENERAL MANUAL, PPOA

(4) Direct procurement method

Direct procurement does not require competitive bidding. Direct procurement is strictly regulated since it is completely devoid of competition and transparency. It is only applicable for the following cases:

i) When there is only one supplier who can supply the goods, works or services being procured and there is no reasonable alternative or substitute for the goods, works or services, or

ii) Where the goods being produced are urgent and because of the urgency the available methods of procurement are not practical. This is the situation which can be regarded as an institutional emergency. In such cases the circumstances that gave rise to the urgency were not foreseeable and were not the result of dilatory conduct or negligence on the part of the procuring entity.

(5) Request for quotations method.

Procuring entities may use request for quotations for goods, works and services which are readily available in the market and whose costs are below the set thresholds in schedule one of the regulations. It is mandatory for the procuring entity to have a pre-qualified suppliers list which is maintained for effective use of the request for quotations procurements method.

Procurement of public project applies Standard Tender Document (STD) of Government of Kenya. Following STD would be applicable for wind generation projects.

- Standard tender document for procurement of works (buildings and associated civil engineering works
- Standard tender document for procurement of works (electrical and mechanical)
- Standard tender document for procurement of goods
- Standard tender document for turnkey projects

Wind project has aspect of civil works, building works, electrical works, and procurement of equipment. Thus, wind project category is considered to be a combination of above categories. It needs to select the closest category and modification needs to be made as necessary.

Above STDs are available in the website of Public Procurement Oversight Authority (PPOA). Standard tender documents are required to be used with minor necessary modifications. Use of other tender documents developed by a procuring entity require approval of the PPOA

STD generally consists of the following:

- Section I: Invitation to Tender
- Section II: Instructions to Tenderers
- Section III: Conditions of Contract
- Section IV: Appendix to Conditions of Contract
- Section V: Specifications
- Section VI: Drawings
- Section VII: Bills of Quantities
- Section VIII: Standard Forms

The above components are according to STD of buildings and associated civil engineering works. The contents of other types of STDs are almost the same.

Specific descriptions need to be prepared according to the format. Especially, Specifications, drawings and bills of quantities, and standard forms need to be prepared according to plan and design. It is necessary to consider evaluation so that all tenderers can be evaluated on the same technical and financial base.

The specification needs to strictly specify quantity and quality requirement, guidelines and standards that the supplier shall follow, user training requirement, reporting obligation, and testing and commission. There is a need to conduct supervision of suppliers and specify the quality requirement in the specification to ensure work quality.

For drawings, it is required to include facility and system layout, single line diagram, powerhouse layout, and other buildings and facility for wind system.
For bills of quantities, work and equipment quantity needs to be specified in a table. The bills of quantity table will be referred for inspection for commissioning to assess if the supplier's work is completed.

8.2 Procedure

Generally, procurement procedure will take more than six months. The tendering process consists of the following works:

- Preparation of tender document and specification
- Request for Expression of Interest and Pre-qualification (when pre-qualification is conducted)
- Invitation to tenderer or advertisement of procurement
- Preparation of tender
- Bid opening
- Bid evaluation
- Contract negotiation award

The schedule required for tendering needs to be considered in the project implementation schedule. The procedure and schedule of general national tender process is shown in the table below.

Table 8.2.1 Example of Procurement Schedule

Work Items	M1				M2				M3				M4				M5				M6				M7				M8				M9			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
Preparation of tender document and specification	■	■	■	■	■	■	■	■																												
(Request for Expression of Interest and Pre-qualification)									■	■	■	■																								
Invitation to tenderer or advertise of procurement													■																							
Preparation of tender														■	■	■	■	■																		
Question and reply about tender															■	■	■																			
Bid opening																			■																	
Bid evaluation																				■	■	■	■													
Contract negotiation award																								■	■											
Implementation and contract administration																										■	■	■	■	■	■	■	■	■	■	■

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If funding is provided from an external donor, concurrence process is required in addition to the above.

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JICA / BRIGHT project (2013), Workshop on Small Wind Energy Systems Training Needs Assessment

Project for Establishment of Rural Electrification Model using Renewable Energy in the Republic of Kenya

Guideline for Wind Power

Rural Electrification Authority

Contents of Guideline

CHAPTER 1. INTRODUCTION

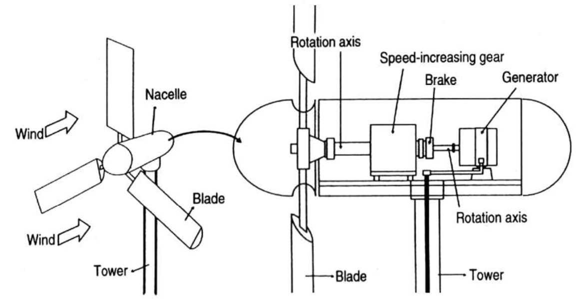
1.1 Objectives of this Guideline

- This guideline has been developed under the cooperation of JICA, REA and MoE&P, for REA and MoE&P staff conducting projects on wind energy development in Kenya.
- Analysis of wind potential is the most important topic in the guideline. This analysis is an essential procedure in the planning of wind power development by project implementation organizations.

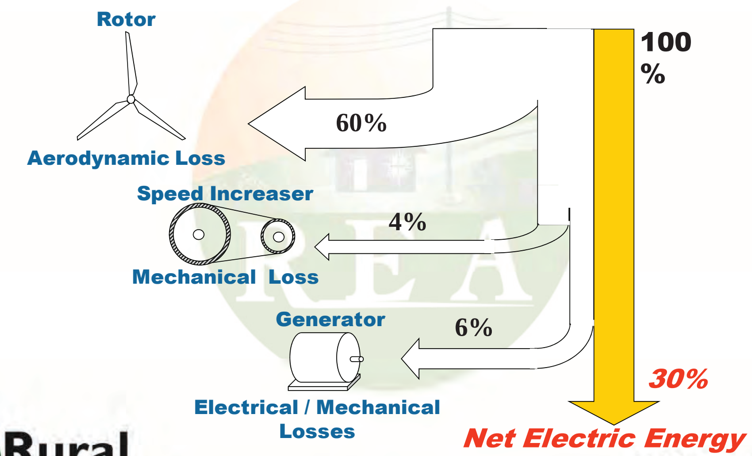
1.2 Applications of Wind Technology

1.2.1 Types of Windmills/Turbines

Energy from Wind Turbine



Components of a Wind Turbine



1.3 Wind Power for Rural Electrification in Kenya

System configuration	Capacity	Main objectives for use
Micro and small class wind turbines	Less than 1kW	Isolated power supply systems Individual households and public facilities such as schools and clinics. Installed for uses such as water pumping and communication in non-electrified communities
Wind hybrid systems	1kW and over Less than 20kW	Isolated power supply systems Public facilities such as schools and clinics Installed as mini grid community systems
Middle and large class wind turbines	20kW and over (middle) 1000 kW and over (large)	Grid-connected systems Installed as wind farms

CHAPTER 2. ANALYSIS OF WIND POTENTIAL

2.1 Measurement of Wind Power

2.1.1 Measurement Plan

- Identification of potential wind development areas;
- Inspection and ranking of candidate sites; and
- Selection of actual tower location(s) within the candidate sites.

2.2.2 Wind Monitoring

Basic and Optimum Parameters

Measured Parameters	Recorded Values
Wind Speed (m/s)	Average Standard Deviation Maximum/Minimum
Wind Direction (degrees)	Average Standard Deviation Maximum Gust Direction
Temperature (^{o}C)	Average Maximum/Minimum
Barometric Pressure (hPa)	Average Maximum/Minimum
Solar Irradiation (W/m^2)	Average Maximum/Minimum

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Wind Power

$$P = \frac{1}{2}\rho A V^3$$

P: Wind power (W)
ρ: Air density (kg/m^3)
A: Swept area (m^2)
V: Wind velocity (m/s)

	A	B	C	D
1	P: wind power	P =	=0.5*C2*C3*C4^3	(W)
2	ρ : Air density	ρ =	1.225	(kg/m^3)
3	A: Swept area	A =	=(C5/2)^2*PI()	(m^2)
4	V: Wind velocity	V =	2	(m/s)
5	D: Roter diameter	D=	10	m

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Air Density

$$\rho = \frac{P}{RT}$$

ρ: Air Density (kg/m^3)
P: Air pressure (N/m^2)
R: Gas Content (287.04 J/kgK)
T: Temperature in Kelvin

	A	B	C
1	ρ: Air Density=	=B2/B4/B5	kg/m^3
2	P:Air pressure (N/m^2)	=B3*100	N/m^2
3		1022	hPa
4	R:Gas Content (287.04 J/kgK)	287.04	J/kgK
5	T:Temperature in Kelvin	=B6+273.15	K
6		16	℃

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Table 2.2.4 Elevation vs. Air Density

Elevation above sea level (m)	Air pressure (hPa)	Air Density at 15℃ (kg/m^3)
0	1013.25	1.225
500	955.23	1.155
1000	901.13	1.089
1500	850.63	1.028
2000	803.47	0.971

	A	B	C
1	Elevation above sea level (m)	Air pressure (hPa)	Air Density at 15℃ (kg/m^3)
2	0	1013.25	1.225
3	500	=$B$2*(1-(0.0065*A3)/(15+0.0065*A3+273.15))^5.257	=B3*100/$C$7/(273.15+15)
4	1000	=$B$2*(1-(0.0065*A4)/(15+0.0065*A4+273.15))^5.257	=B4*100/$C$7/(273.15+15)
5	1500	=$B$2*(1-(0.0065*A5)/(15+0.0065*A5+273.15))^5.257	=B5*100/$C$7/(273.15+15)
6	2000	=$B$2*(1-(0.0065*A6)/(15+0.0065*A6+273.15))^5.257	=B6*100/$C$7/(273.15+15)
7		Gas Content (J/kgK):	287.04

Vertical Wind Speed

$$V = \left(\frac{H}{H_0}\right)^{\alpha} V_0$$

V_0: Wind speed at original height
V: Wind speed at new height
H_o: Original height
H: New height
α: Wind shear exponent

	A	B	C	D
1	V:	Wind speed at new height	=C2*(C4/C3)^C5	m/s
2	V_0:	Wind speed at original height	5	m/s
3	H_o:	Original height	10	m
4	H:	New height	80	m
5	α:	Wind shear exponent	0.16	

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Table 2.2.7 Wind Shear Exponent

Terrain	Wind Shear Exponent α
Coastal areas	0.11
Cut grass	0.14
Short-grass prairies	0.16
Crops, tall-grass prairies	0.19
Scattered trees and hedges	0.24
Trees, hedges, a few buildings	0.29
Suburbs	0.31
Woodlands	0.43

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Wind Shear Exponent

$$\alpha = \frac{\ln\left(\frac{V}{V_0}\right)}{\ln\left(\frac{H}{H_0}\right)}$$

	A	B	C	D
1	V	Wind speed at higher height	=C2*(C4/C3)^C5	m/s
2	V_0	Wind speed at lower height	5	m/s
3	H_o	Lower height	20	m
4	H	Higher height	40	m
5	α	Wind shear exponent	0.16	

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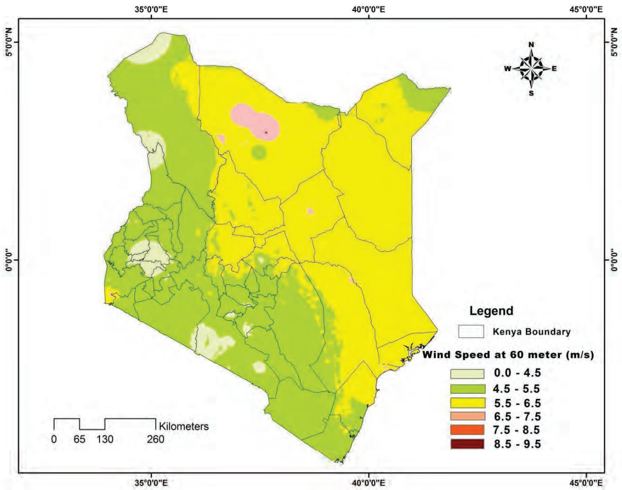
2.3 Wind Potential Map (60m a.g.l)



Data for evaluation (1)

	Items	Term	Purpose	Procedure
Wind Condition	Average Wind Speed (m/s)	Annual Monthly	Evaluation of wind speed	Average Wind Speed ＝Sum of all hourly averaged value in of monitoring term / No. of data
	Wind Speed Frequency Distribution(%)	Annual	Evaluate characteristic of wind speed by wind speed frequency distribution	A wind speed class is established every 1m/s and calculates the relative frequency of each class
	Wind Direction Frequency Distribution (%)	Annual	Clarify prevailing wind direction	All wind direction is divided into 16 direction and accumulate in mean wind direction
	Directional Wind Speed (m/s)	Annual	Clarify prevailing wind direction to consider siting of wind turbines	An arithmetic average based on hour mean wind speed is calculated every direction
	Wind Speed Directional Frequency Distribution (%)	Annual	Clarify prevailing wind direction to consider siting of wind turbines	Relative frequency of each wind speed class (1m/s step) is calculated every azimuth
	Diurnal Wind Speed (m/s)	Diurnal Annual	Time variability of wind speed is evaluated for operational plan of the wind turbines	The average hourly wind speed of each month is calculated and clarifies the transaction by chart
	Turbulence intensity	Annual	Fluctuation properties of the wind speed and the direction with large wind speed fluctuation is clarified	It is calculated for the wind speed for all azimuth direction and each direction. Intensity of turbulence =standard deviation of wind speed / mean wind speed
	Vertical Wind Speed	Annual	Power index to predict wind speed at certain height is calculated and clarified vertical distribution of the wind speed	Each monitoring height and the wind speed are substituted for following formula and calculate it by a least squares $V/V1 = (Z/Z1)^{1/n}$

Data for evaluation (2)

Wind Energy	Utilization Factor	Annual	Operational conditions of the wind turbine are clarified	It accumulates from the high wind speed side in wind speed relative frequency and calculates cumulative relative frequency. Utilization Factor = Cumulative relative frequency higher than cut-in wind speed - Cumulative relative frequency higher than cut-out wind speed
	Power Availability (Annual Power Output) ($kWh/m^2/year$)	Annual Monthly	Amount of power output that can be acquired from wind power generation is evaluated	It is accumulated in annual power output at every wind speed based on power curve of wind turbine and wind speed relative frequency.
	Capacity Factor	Annual Monthly	Possibility of the introduction of the wind power generation is evaluated	Capacity factor = power output / (reted power output x operational hours)

a. Average Wind Speed

- The sites where annual average wind speeds **exceed 6 m/s at 30 m** above ground level are acceptable for wind power development.

$$\text{Average Wind Speed (m/s)} = \frac{\textit{Sum of hourly average value in monitoring period (m/s)}}{\textit{Number of monitored data}}$$

Table 2.4.2 Datasheet and the Result of Wind Speed Evaluation

	A	B	C	D	E	F	G	H	I	J	K
1	date	time	Wind Speed Avg. (m/s) 20m (a.g.l)	Wind Speed Max. (m/s) 20m (a.g.l)	Wind Speed Min. (m/s) 20m (a.g.l)	Std. deviation 20m (a.g.l) (sig)		Wind Class	Range of Wind Speed (m/s)	No. of Data	Frequency (%)
2			**5.70**	**7.56**	**3.97**	**0.70**		0	0<V<0.5	0	0.0%
3	01.09.2010	0:00:00	6.5	8.7	4.5	0.7		1	0.5<=V<1.5	67	1.6%
4	01.09.2010	0:10:00	6.1	8.4	4.2	0.7		2	1.5<=V<2.5	247	5.7%
5	01.09.2010	0:20:00	6.3	7.7	4.8	0.6		3	2.5<=V<3.5	449	10.4%
6	01.09.2010	0:30:00	6.6	8.1	5.1	0.5		4	3.5<=V<4.5	568	13.1%
7	01.09.2010	0:40:00	6.6	8.8	5.2	0.7		5	4.5<=V<5.5	684	15.8%
8	01.09.2010	0:50:00	6.8	8.4	5.4	0.5		6	5.5<=V<6.5	765	17.7%
9	01.09.2010	1:00:00	6.4	7.6	4.8	0.5		7	6.5<=V<7.5	617	14.3%
10	01.09.2010	1:10:00	5.8	7.5	4.6	0.4		8	7.5<=V<8.5	430	10.0%
11	01.09.2010	1:20:00	5.8	6.8	4.6	0.4		9	8.5<=V<9.5	252	5.8%
12	01.09.2010	1:30:00	5.8	7.4	4.6	0.5		10	9.5<=V<10.5	113	2.6%
13	01.09.2010	1:40:00	5.8	7.4	4.5	0.5		11	10.5<=V<11.5	62	1.4%
14	01.09.2010	1:50:00	6	7.6	4.9	0.5		12	11.5<=V<12.5	33	0.8%
15	01.09.2010	2:00:00	5.3	6.8	4.4	0.4		13	12.5<=V<13.5	23	0.5%
16	01.09.2010	2:10:00	4.8	5.7	4	0.3		14	13.5<=V<14.5	10	0.2%
17	01.09.2010	2:20:00	4.9	6.2	4	0.4		15	14.5<=V<15.5	0	0.0%
18	01.09.2010	2:30:00	5	6.3	4.1	0.4		16	15.5<=V<16.5	0	0.0%
19	01.09.2010	2:40:00	4.7	5.7	4	0.3		17	16.5<=V<17.5	0	0.0%
20	01.09.2010	2:50:00	4.2	4.9	3.5	0.2		18	17.5<=V<18.5	0	0.0%
21	01.09.2010	3:00:00	4.2	5.2	3.5	0.3		19	18.5<=V<19.5	0	0.0%
22	01.09.2010	3:10:00	4.2	5.1	3.4	0.3		20	19.5<=V<20.5	0	0.0%
23	01.09.2010	3:20:00	4.5	5.7	3.5	0.4				4320	100%
24	01.09.2010	3:30:00	5	6.3	3.9	0.5					
-	01.09.2010	3:40:00	5.2	6.4	4.1	0.4					
-	01.09.2010	3:50:00	4.8	6.1	3.6	0.5					

Figure 2.4.1 Wind Speed Frequency

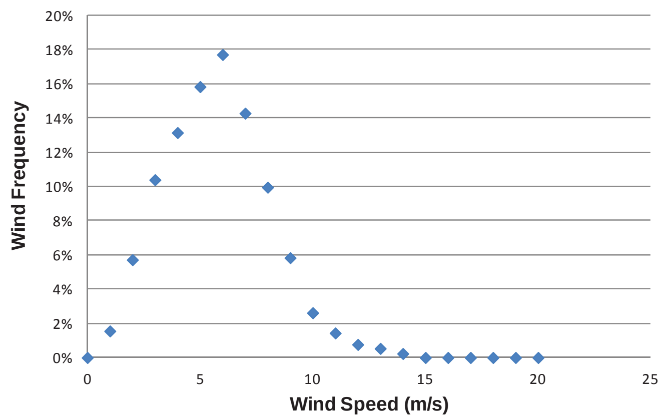


Table 2.4.3 Spreadsheet for sorting Wind Speed Data

Wind Class	Range of Wind Speed (m/s)	No. of Data	Frequency (%)
0	0<V<0.5	=COUNTIF(C$3:C$5000,"<0.5")	=J2/$J$23
1	0.5<=V<1.5	=COUNTIF(C$3:C$5000,"<1.5")-COUNTIF(C$3:C$5000,"<0.5")	=J3/$J$23
2	1.5<=V<2.5	=COUNTIF(C$3:C$5000,"<2.5")-COUNTIF(C$3:C$5000,"<1.5")	=J4/$J$23
3	2.5<=V<3.5	=COUNTIF(C$3:C$5000,"<3.5")-COUNTIF(C$3:C$5000,"<2.5")	=J5/$J$23
4	3.5<=V<4.5	=COUNTIF(C$3:C$5000,"<4.5")-COUNTIF(C$3:C$5000,"<3.5")	=J6/$J$23
5	4.5<=V<5.5	=COUNTIF(C$3:C$5000,"<5.5")-COUNTIF(C$3:C$5000,"<4.5")	=J7/$J$23
6	5.5<=V<6.5	=COUNTIF(C$3:C$5000,"<6.5")-COUNTIF(C$3:C$5000,"<5.5")	=J8/$J$23
7	6.5<=V<7.5	=COUNTIF(C$3:C$5000,"<7.5")-COUNTIF(C$3:C$5000,"<6.5")	=J9/$J$23
8	7.5<=V<8.5	=COUNTIF(C$3:C$5000,"<8.5")-COUNTIF(C$3:C$5000,"<7.5")	=J10/$J$23
9	8.5<=V<9.5	=COUNTIF(C$3:C$5000,"<9.5")-COUNTIF(C$3:C$5000,"<8.5")	=J11/$J$23
10	9.5<=V<10.5	=COUNTIF(C$3:C$5000,"<10.5")-COUNTIF(C$3:C$5000,"<9.5")	=J12/$J$23
11	10.5<=V<11.5	=COUNTIF(C$3:C$5000,"<11.5")-COUNTIF(C$3:C$5000,"<10.5")	=J13/$J$23
12	11.5<=V<12.5	=COUNTIF(C$3:C$5000,"<12.5")-COUNTIF(C$3:C$5000,"<11.5")	=J14/$J$23
13	12.5<=V<13.5	=COUNTIF(C$3:C$5000,"<13.5")-COUNTIF(C$3:C$5000,"<12.5")	=J15/$J$23
14	13.5<=V<14.5	=COUNTIF(C$3:C$5000,"<14.5")-COUNTIF(C$3:C$5000,"<13.5")	=J16/$J$23
15	14.5<=V<15.5	=COUNTIF(C$3:C$5000,"<15.5")-COUNTIF(C$3:C$5000,"<14.5")	=J17/$J$23
16	15.5<=V<16.5	=COUNTIF(C$3:C$5000,"<16.5")-COUNTIF(C$3:C$5000,"<15.5")	=J18/$J$23
17	16.5<=V<17.5	=COUNTIF(C$3:C$5000,"<17.5")-COUNTIF(C$3:C$5000,"<16.5")	=J19/$J$23
18	17.5<=V<18.5	=COUNTIF(C$3:C$5000,"<18.5")-COUNTIF(C$3:C$5000,"<17.5")	=J20/$J$23
19	18.5<=V<19.5	=COUNTIF(C$3:C$5000,"<19.5")-COUNTIF(C$3:C$5000,"<18.5")	=J21/$J$23
20	19.5<=V<20.5	=COUNTIF(C$3:C$5000,"<20.5")-COUNTIF(C$3:C$5000,"<19.5")	=J22/$J$23
		=SUM(J2:J22)	=SUM(K2:K22)

Distributions

Weibull Distribution

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right]$$

k: shape factor
c: scale factor

Rayleig Distribution

$$f(V) = \frac{\pi}{2}\frac{V}{\overline{V}^2} \exp\left[-\frac{\pi}{4}\left(\frac{V}{\overline{V}}\right)^2\right]$$

Table 2.4.4 Spreadsheet for Wind Speed Distribution (Rayleigh)

	A	B	C	D	E	F	G	H
1	Weibull shape parameter k	2			Wind Speed bin V (m/s)	from	to	Wind Frequency (f)
2	Weibull scale parameter c	7.7			0	0	0.5	0.422%
3	Wind Speed at anemo. high	6.0	m/s		1	0.5	1.5	3.309%
4	Anemo. Height	30	m		2	1.5	2.5	6.292%
5	Terrain roughness	0.25	m		3	2.5	3.5	8.676%
6	Hub hight	50	m		4	3.5	4.5	10.281%
7	Wind Speed at hub high	6.82	m/s		5	4.5	5.5	11.042%
8					6	5.5	6.5	11.009%
9					7	6.5	7.5	10.317%
10					8	7.5	8.5	9.157%
11					9	8.5	9.5	7.736%
12					10	9.5	10.5	6.240%
13					11	10.5	11.5	4.818%
14					12	11.5	12.5	3.568%
15					13	12.5	13.5	2.536%
16					14	13.5	14.5	1.733%
17					15	14.5	15.5	1.139%
18					16	15.5	16.5	0.720%
19					17	16.5	17.5	0.439%
20					18	17.5	18.5	0.258%
21					19	18.5	19.5	0.146%
22					20	19.5	20.5	0.080%
23					21	20.5	21.5	0.042%
24					22	21.5	22.5	0.021%
25					23	22.5	23.5	0.010%
26					24	23.5	24.5	0.005%
27					25	24.5	25.5	0.002%
28					26	25.5	26.5	0.001%
29								100%

Figure 2.4.2 Wind Speed Frequency using Rayleigh Distribution

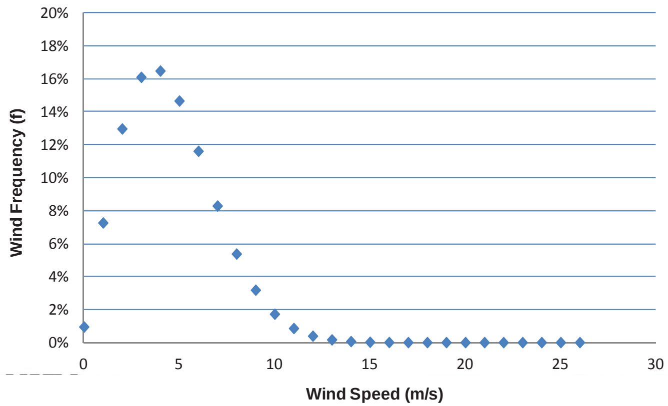


Table 2.4.5 Spreadsheet for Weibull Parameters and Height Correction

	A	B	C
1	Weibull shape parameter k	2	
2	Weibull scale parameter c	=B7/EXP(GAMMALN(1+1/B1))	
3	Wind Speed at anemo. high	4	m/s
4	Anemo. Height	30	m
5	Terrain roughness	0.25	m
6	Hub hight	50	m
7	Wind Speed at hub high	=B3*(B6/B4)^(B5)	m/s

Table 2.4.6 Spreadsheet for Weibull Parameters and Height Correction

	D	E	F	G	H
1		Wind Speed bin V (m/s)	from	to	Wind Probability (f)
2		0	0	0.5	=WEIBULL(G2,$B$1,$B$2,TRUE)-WEIBULL(F2,$B$1,$B$2,TRUE)
3		1	0.5	1.5	=WEIBULL(G3,$B$1,$B$2,TRUE)-WEIBULL(F3$B$1,$B$2,TRUE)
4		2	1.5	2.5	=WEIBULL(G4,$B$1,$B$2,TRUE)-WEIBULL(F4,$B$1,$B$2,TRUE)
5		3	2.5	3.5	=WEIBULL(G5,$B$1,$B$2,TRUE)-WEIBULL(F5,$B$1,$B$2,TRUE)
6		4	3.5	4.5	=WEIBULL(G6,$B$1,$B$2,TRUE)-WEIBULL(F6,$B$1,$B$2,TRUE)
7		5	4.5	5.5	=WEIBULL(G7,$B$1,$B$2,TRUE)-WEIBULL(F7,$B$1,$B$2,TRUE)
8		6	5.5	6.5	=WEIBULL(G8,$B$1,$B$2,TRUE)-WEIBULL(F8,$B$1,$B$2,TRUE)
9		7	6.5	7.5	=WEIBULL(G9,$B$1,$B$2,TRUE)-WEIBULL(F9,$B$1,$B$2,TRUE)
10		8	7.5	8.5	=WEIBULL(G10,$B$1,$B$2,TRUE)-WEIBULL(F10,$B$1,$B$2,TRUE)
11		9	8.5	9.5	=WEIBULL(G11,$B$1,$B$2,TRUE)-WEIBULL(F11,$B$1,$B$2,TRUE)
12		10	9.5	10.5	=WEIBULL(G12,$B$1,$B$2,TRUE)-WEIBULL(F12,$B$1,$B$2,TRUE)
13		11	10.5	11.5	=WEIBULL(G13,$B$1,$B$2,TRUE)-WEIBULL(F13,$B$1,$B$2,TRUE)
14		12	11.5	12.5	=WEIBULL(G14,$B$1,$B$2,TRUE)-WEIBULL(F14,$B$1,$B$2,TRUE)
15		13	12.5	13.5	=WEIBULL(G15,$B$1,$B$2,TRUE)-WEIBULL(F15,$B$1,$B$2,TRUE)
16		14	13.5	14.5	=WEIBULL(G16,$B$1,$B$2,TRUE)-WEIBULL(F16,$B$1,$B$2,TRUE)
17		15	14.5	15.5	=WEIBULL(G17,$B$1,$B$2,TRUE)-WEIBULL(F17,$B$1,$B$2,TRUE)
18		16	15.5	16.5	=WEIBULL(G18,$B$1,$B$2,TRUE)-WEIBULL(F18,$B$1,$B$2,TRUE)
19		17	16.5	17.5	=WEIBULL(G19,$B$1,$B$2,TRUE)-WEIBULL(F19,$B$1,$B$2,TRUE)
20		18	17.5	18.5	=WEIBULL(G20,$B$1,$B$2,TRUE)-WEIBULL(F20,$B$1,$B$2,TRUE)
21		19	18.5	19.5	=WEIBULL(G21,$B$1,$B$2,TRUE)-WEIBULL(F21,$B$1,$B$2,TRUE)
22		20	19.5	20.5	=WEIBULL(G22,$B$1,$B$2,TRUE)-WEIBULL(F22,$B$1,$B$2,TRUE)
23		21	20.5	21.5	=WEIBULL(G23,$B$1,$B$2,TRUE)-WEIBULL(F23,$B$1,$B$2,TRUE)
24		22	21.5	22.5	=WEIBULL(G24,$B$1,$B$2,TRUE)-WEIBULL(F24,$B$1,$B$2,TRUE)
25		23	22.5	23.5	=WEIBULL(G25,$B$1,$B$2,TRUE)-WEIBULL(F25,$B$1,$B$2,TRUE)
26		24	23.5	24.5	=WEIBULL(G26,$B$1,$B$2,TRUE)-WEIBULL(F26,$B$1,$B$2,TRUE)
27		25	24.5	25.5	=WEIBULL(G27,$B$1,$B$2,TRUE)-WEIBULL(F27,$B$1,$B$2,TRUE)
28		26	25.5	26.5	=WEIBULL(G28,$B$1,$B$2,TRUE)-WEIBULL(F28,$B$1,$B$2,TRUE)
29					=SUM(H2:H28)

Figure 2.4.3 Wind Axis

If the relative frequency of annual wind direction is **more than 60% in the wind axis**, the wind direction can be considered as stable. (Wind axis is defined as the direction of the prevailing wind and the two immediate directions on both sides, and the symmetric directions of these three directions. In total, 6 out of the 16 azimuth angles are designated as the wind axis. The following figure shows an example of wind-axis (SSW, SW, WSW and ENE, NE, NNE)) marked by the red line.

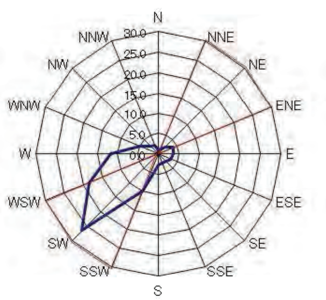


Table 2.4.7 Datasheet and the Result of Wind Direction Evaluation

	A	B	C	D	E	F	G	H	I	J	K
1	date	time	Direction		No.	Direction (degree)			Direction	Data	
2			(40m)							No.	%
3	01.09.2010	0:00:00	107		1	0	<V<	11.25	N	99	2.5%
4	01.09.2010	0:10:00	107		2	11.25	<=V<	33.75	NNE	73	1.8%
5	01.09.2010	0:20:00	106		3	33.75	<=V<	56.25	NE	67	2.2%
6	01.09.2010	0:30:00	110		4	56.25	<=V<	78.75	NEE	170	6.2%
7	01.09.2010	0:40:00	109		5	78.75	<=V<	101.25	E	830	27.7%
8	01.09.2010	0:50:00	109		6	101.25	<=V<	123.75	SEE	1840	36.2%
9	01.09.2010	1:00:00	110		7	123.75	<=V<	146.25	SE	593	7.9%
10	01.09.2010	1:10:00	105		8	146.25	<=V<	168.75	SSE	73	1.4%
11	01.09.2010	1:20:00	100		9	168.75	<=V<	191.25	S	52	1.3%
12	01.09.2010	1:30:00	98		10	191.25	<=V<	213.75	SSW	37	1.1%
13	01.09.2010	1:40:00	92		11	213.75	<=V<	236.25	SW	28	0.7%
14	01.09.2010	1:50:00	90		12	236.25	<=V<	258.75	SWW	61	1.4%
15	01.09.2010	2:00:00	93		13	258.75	<=V<	281.25	W	90	2.4%
16	01.09.2010	2:10:00	101		14	281.25	<=V<	303.75	NWW	97	2.3%
17	01.09.2010	2:20:00	96		15	303.75	<=V<	326.25	NW	99	2.5%
18	01.09.2010	2:30:00	104		16	326.25	<=V<	348.75	NNW	111	2.6%
19	01.09.2010	2:40:00	108		1	348.75	<=V<	360			
20	01.09.2010	2:50:00	95							4320	100%
21	01.09.2010	3:00:00	88								
-	01.09.2010	3:10:00	92								
	01.09.2010	3:20:00	94								

a. Wind Power Density

- Annual wind energy density should be more than **240 W/m² at 30 meters above ground level**.

$$P_d = \frac{1}{2} \frac{\rho \sum V^3}{T_0}$$

P_d: Wind Power Density (W/m²)
ρ: Air Density (kg/m³)
V: Hourly average wind speed (m/s)
T_0: Number of monitoring hours

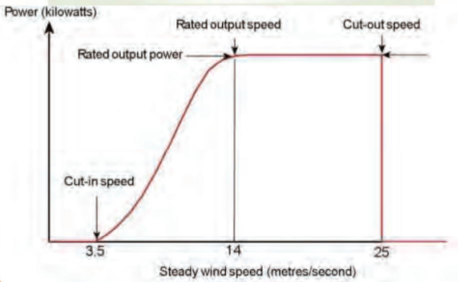
b. Capacity Factor of Wind Turbine

- Annual capacity factor should be **more than 20%.**

$$\text{Annual Capacity Factor (\%)} = \frac{\text{Annual Energy Output (kWh)}}{\text{Rated Power Output (kW)} \times 8760(\text{hr.})}$$

Figure 2.4.4 Power Curve of a Typical Wind Turbine

Cut-in wind speed：3～4 m/s
Rated wind speed：12～16 m/s (dependent on wind turbine performance)
Cut-out wind speed：24～25 m/s



Power Output

Annual Energy Output = 1.85 (kW) × 8760 (hr.)
= 16,206 kWh/Year

Monthly Energy Output = 1.85 (kW) × 720 (hr.)
= 1,322 kWh/Month

Daily Energy Output = 1.85 (kW) × 24 (hr.)
= 44.4 kWh/day

Capacity Factor = 1.85 / 7.5 =24.6%

Wind Class	Range of Wind Speed (m/s)	Wind Speed Probability (f)	×	Power: (p) (kW)	=	Net kW (kW)
0	0<V<0.5	0%		0.0		0.00
1	0.5<=V<1.5	2%		0.0		0.00
2	1.5<=V<2.5	6%		0.0		0.00
3	2.5<=V<3.5	10%		0.0		0.00
4	3.5<=V<4.5	13%		0.3		0.03
5	4.5<=V<5.5	16%		0.8		0.13
6	5.5<=V<6.5	18%		1.7		0.29
7	6.5<=V<7.5	14%		2.6		0.36
8	7.5<=V<8.5	10%		3.7		0.36
9	8.5<=V<9.5	6%		4.9		0.28
10	9.5<=V<10.5	3%		6.2		0.16
11	10.5<=V<11.5	1%		7.5		0.11
12	11.5<=V<12.5	1%		8.0		0.06
13	12.5<=V<13.5	1%		8.0		0.04
14	13.5<=V<14.5	0%		8.0		0.02
15	14.5<=V<15.5	0%		7.0		0.00
16	15.5<=V<16.5	0%		5.0		0.00
17	16.5<=V<17.5	0%		2.7		0.00
18	17.5<=V<18.5	0%		3.0		0.00
19	18.5<=V<19.5	0%		3.0		0.00
20	19.5<=V<20.5	0%		3.0		0.00
		100%				1.85

Chapter 3 &4

- CHAPTER 3. MICRO-SMALL WIND SYSTEMS
- CHAPTER 4. WIND-DIESEL HYBRID SYSTEM

WIND-DIESEL HYBRID SYSTEM

- **4.1 Preparation (Demand Survey, Output Estimation..)**
- Power demands should be studied to design an appropriate wind hybrid system.
- Table 4.1.1 shows typical power potential of electrical equipment and hours of use.
- Electrical demand is estimated using the power potential of electrical equipment and operational hours.
- The power potential of equipment should be confirmed in demand survey.

Table 4.1.1 Potential of Electrical Equipment

Electrical Equipment (AC)	Power (W)	Hours of Use
Television (Colour, 30 inch)	70 -150	3-8
DVD	20 - 40	1-2
TV, DVD - stand by	10	21 – 16
Light (LED)	10	3-8
Computer (Laptop)	20 - 150	1-6
Printer (Inkjet)	15 - 30	0.5 – 1.0
Blender	250	< 0.5
Radio	5 - 50	1 - 8
Refrigerator	150 - 600	24

Table 4.1.2 Estimation of Power Demand (Household)

Electrical Equipment (AC)	Power (W)	Hours of Use
Television (Colour, 30 inch)	70 -150	3-8
DVD	20 - 40	1-2
TV, DVD - stand by	10	21 – 16
Light (LED)	10	3-8
Computer (Laptop)	20 - 150	1-6
Printer (Inkjet)	15 - 30	0.5 – 1.0
Blender	250	< 0.5
Radio	5 - 50	1 - 8
Refrigerator	150 - 600	24

Estimated Demand Curve

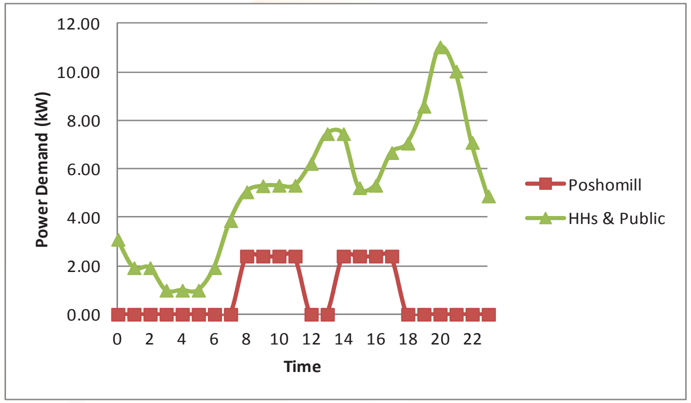
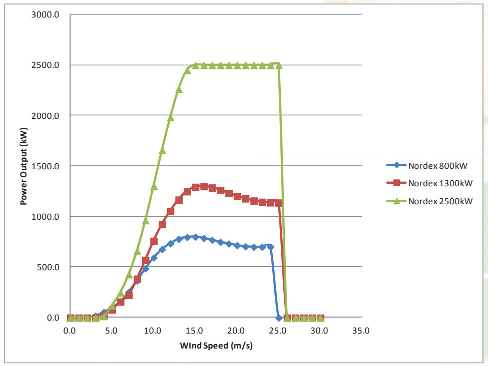


Fig.4.2.1 Performance of Wind Turbines



Net kW	Layer Electronics GE-200, 20kW	Net kW	Northern Power 60kW	Net kW	Northern Power 100kW
Wind Speed Bin: V (m/s)	Power: p (kW)	Wind Speed Bin: V (m/s)	Power: p (kW)	Wind Speed Bin: V (m/s)	Power: p (kW)
0	0	0.0	0	0.0	0.0
1	0	1.0	-0.6	1.0	0.0
2	0	2.0	-0.6	2.0	0.0
3	0.6	3.0	0.6	3.0	0.5
4	1.2	4.0	6.1	4.0	4.1
5	1.7	5.0	12.8	5.0	10.5
6	2.4	6.0	21.9	6.0	19.0
7	3.4	7.0	32.0	7.0	29.4
8	4.8	8.0	41.5	8.0	41.0
9	6.9	9.0	48.9	9.0	54.3
10	9.8	10.0	52.8	10.0	66.8
11	14.0	11.0	55.3	11.0	77.7
12	20.0	12.0	57.1	12.0	86.4
13	25.4	13.0	58.8	13.0	92.8
14	25.4	14.0	59.9	14.0	97.8
15	25.4	15.0	59.7	15.0	100.0
16	25.4	16.0	59.3	16.0	99.9
17	25.4	17.0	58.4	17.0	99.2
18	25.4	18.0	57.1	18.0	99.4
19	25.4	19.0	55.6	19.0	97.5
20	25.4	20.0	54.0	20.0	96.8
21	25.4	21.0	52.5	21.0	96.4
22	25.4	22.0	51.0	22.0	96.3
23	25.4	23.0	49.9	23.0	96.8
24	25.4	24.0	49.1	24.0	98.0
25	25.4	25.0	48.8	25.0	99.2

Important parameters for design of wind - diesel hybrid system

- Wind profile
- Demand curve of existing diesel generator
- Correlation between wind pattern and demand curve
- Power quality requirement
- Ease of maintenance and availability of spare parts and consumable supplies

Table 4.3.1 Penetration Class of Wind - Diesel Systems

Penetration Class	Operating Characteristics	Peak Instantaneous Penetrations	Annual Average Penetration
LOW	• Diesel runs full-time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
MEDIUM	• Diesel runs full-time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed • Requires relatively simple control system	50%–100%	20%–50%
HIGH	• Diesel may be shut down during high wind availability • Auxiliary components are required to regulate voltage and frequency • Requires sophisticated control system	100%–400%	50%–150%

Source: Wind Energy: Renewable Energy and Environment, Second Edition

Estimation of Wind - Diesel Penetration Ratio

Case-1: Installation of wind turbine at existing diesel power station

(1) Calculation of average penetration ratio

1) Study the operational record of existing diesel generator and calculate the following information.

- Annual Energy Output (kWh/year)
- Monthly Energy Output (kWh/month)
- Diurnal Energy Output (kWh/day)

2) Estimate power output of candidate wind turbine to calculate the following information.

- Annual Energy Output (kWh/year)
- Monthly Energy Output (kWh/month)
- Diurnal Energy Output (kWh/day)

3) Calculate average penetration ratio

$$\text{Annual Energy Penetration} = \frac{\text{Annual Wind Energy Output (kWh)}}{\text{Annual Primary Energy Demand (kWh)}} \times 100(\%)$$

Wind - Diesel Penetration

	Diesel	Wind	Penetration Ratio
Low Penetration	100 kW (100kW x 50% x 8760 hr.= 438,000 kWh)*1	25 kW (25 kW x 25% x 8760 hr. = 54,750 kWh)	Energy Penetration; 11 % $\left(\frac{54,750}{438,000+54,750}\right)$
	Minimum Demand 25kW	Maximum Power 25 kW	Power Penetration; 50 % $\left(\frac{25}{25+25}\right)$
Middle Penetration	100 kW	50 kW (50 kW x 25% x 8,760 hr. = 109,500 kWh)	Energy Penetration; 20 % $\left(\frac{109,500}{438,000+109,500}\right)$
	Minimum Demand 25 kW	Maximum Power 50kW	Power Penetration; 67 % $\left(\frac{50}{25+50}\right)$
High Penetration (Battery, flywheel, etc.)	100 kW (shutdown @ high wind)	150 kW (150 kW x 25% x 8760 hr. = 328,500 kWh) Storage: 300 kWh (50kW x 6hr x 365 day)	Energy Penetration; 57 % $\left(\frac{328,500+109,500}{438,000+328,500}\right)$
	Minimum Demand 25kW	Maximum Power 150kW	Power Penetration; 114 % $\left(\frac{150+50}{25+150}\right)$

A. Habaswein Power Station

Diesel: 500 kVA

Wind:20 kW x 3

PV: 30 kW

B. Marsabit Power Station

Diesel: 2000 kVA (1000 kVA x2)

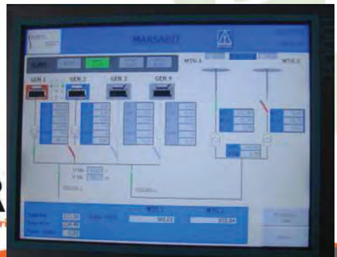
Wind: 490 kW (245 kW x 2)

A. Habaswein Power Station




B. Marsabit Power Station






CHAPTER 5. OPERATION & MAINTENANCE

- In agreement with manufacturer and/or supplier, high specialty O&M services to be included. Summarized in Table 5.1.1
- The following should be considered;
- Contract for monitoring operation
- Contract for maintenance (periodic and irregular inspection)
- Contract for repair/modification
- Spare parts, Tools and fixtures e.t.c

CHAPTER 6. ECONOMIC CONSIDERATIONS

Benefit from Wind

The cost of installation of wind turbine is simply the cost of the wind turbine, tower, wiring installation and taxes and so on.

One of the advantages using wind energy over generating electricity by conventional means is the free fuel. The table below shows sample benefit from an installation of wind turbine with 15 kW. The benefit is the diesel cost which replaced by power supplied from the wind turbine.

Generation capacity of the wind turbine	15	kW
Plant factor (Wind)	21%	
Operation hour per day	24	Hours
Operation day per year	360	days
Annual power generation (Wind)	26,957	kWh/Y
Life time of the wind turbine	20	Years
OM cost of the generation system (% of the investment)	2.0%	
Diesel fuel cost per litter	105.0	kSh/litter
Fuel consumption	0.67	litter/kWh
Fuel cost per kWh	70.35	kSh/kWh

Benefit (Replaced Diesel Cost) 1,896,411 kSh/Y

Rural Electrification Authority

Lighting up rural Kenya

CHAPTER 7. ENVIRONMENT AND SOCIAL CONSIDERATION

Renewable Energy Projects and necessity of EIA

Renewable Energy Projects (PV, Mini hydro, Bio-gas and Wind power systems) falls under “No. 10 Electrical Infrastructure” in the “Second Schedule” of EMCA. Therefore, all Renewable Energy Projects are naturally subject to the EIA procedures.

Rural Electrification Authority

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CHAPTER 8. PROCUREMENT

- The procurement needs to be conducted according to Public Procurement and Disposal Act 2005 and the Public Procurement and Disposal Regulations 2006 stipulated by the Government of Kenya.
- Wind projects have the components of civil works, electrical and mechanical works, and goods. It is necessary to combine applicable descriptions in the tender document.

Rural Electrification Authority

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Thank you

Rural Electrification Authority

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Simple Pre-Feasibility Study
on
Wind Power Development in Baragoi

Rural Electrification Authority

Ministry of Energy and Petroleum

Simple Pre-Feasibility Study on Wind Power Development in Baragoi

Contents

1. INTRODUCTION

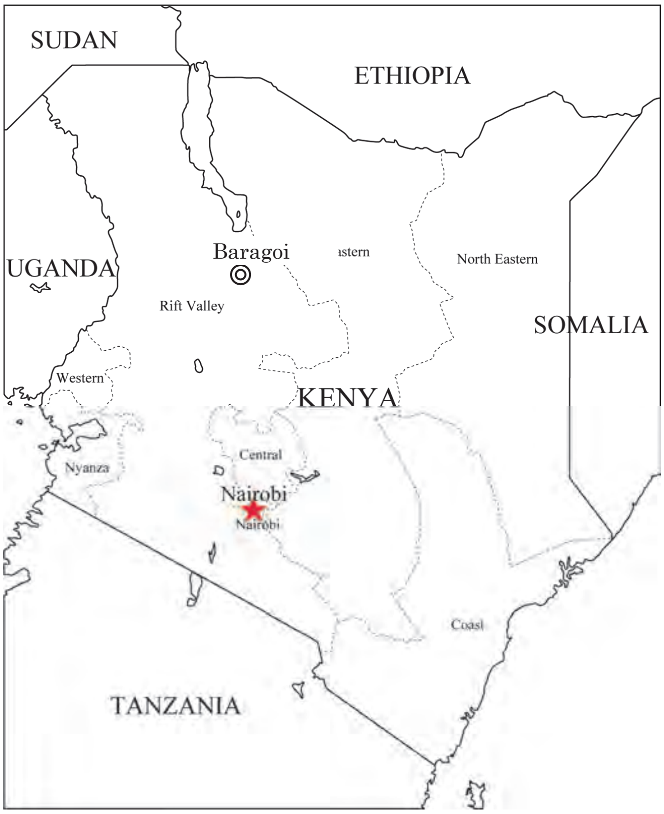
1.1 Purpose of Simple Pre-F/S

The purpose of this pre - feasibility study is to evaluate the wind potential at Baragoi in Samburu County and to prepare conceptual design for wind - diesel hybrid system.

Wind - diesel power plants can be used for power supply in autonomous systems where a connection to the national grid is either impossible or too expensive due to long transmission line. The diesel generators provide power when needed, whereas the wind turbines serve to reduce the diesel fuel consumption. The most important purpose of a Wind -Diesel Hybrid system is to reduce the consumption of diesel fuel. In general, isolated diesel power stations are located in remote areas, and transportation and oil storage costs can therefore be reduced.

1.2 Location and Topography

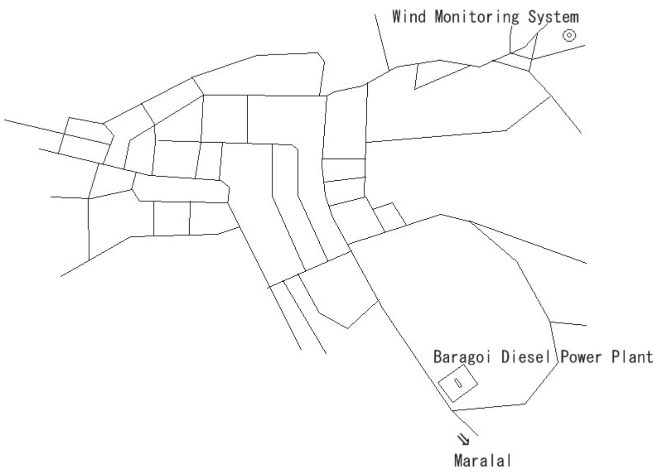
Samburu County is located in Rift Valley and constitutes of three Sub-Counties; Samburu North, Samburu Central and Samburu East. Baragoi is located South of Lake Turkana Lake in Samburu North Sub-County. Baragoi is located around 100 km from Maralal, where Samburu County Government is located. The distance between Maralal and Nairobi is 352 km. The total population of Baragoi is 31,043 (2009 census) comprised mostly of Samburu and Turkana tribes. The following figure shows the location of Baragoi.



Prepared by JET

Figure 1 Location of Baragoi

The diesel power station in Baragoi is located at the outskirts of Baragoi town. The location of the power station is N 1.46’44’’, E 36.47’26’’, at an altitude of about 1280 meters above sea level.



Prepared by JET

Figure 2 Center of Baragoi Town

1.3 Climate

Baragoi is semi-arid, with temperatures averaging between 25°C during the coldest months (June and July) and 33°C during the hottest months (January to March). The rainfall is low and erratic, with a bimodal distribution. The total annual precipitation averages 700mm, with April and November being the wettest months while the driest months are between July and September.

2. SOCIO - ECONOMIC CONDITIONS AND POWER DEMAND

The Government of the Republic of Kenya will implement the “Project for Establishment of Rural Electrification Model using Renewable Energy” in Cooperation with JICA. REA and MoE&P are responsible in the Project.

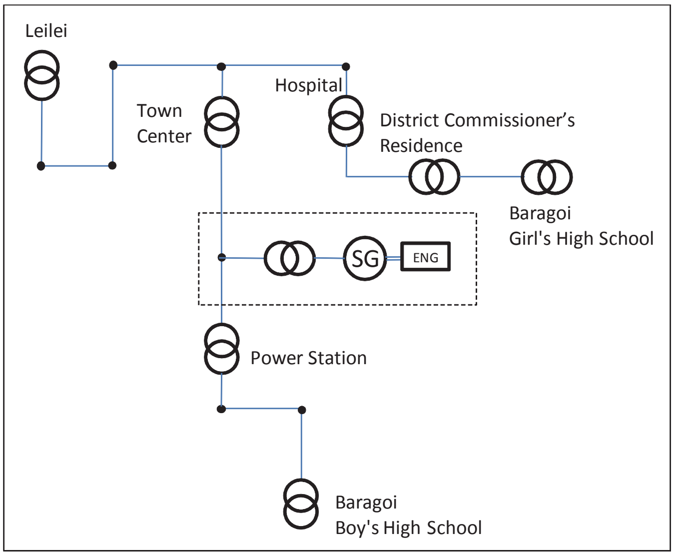
2.1 Socio - Economic Conditions

Samburu County is made up of three Sub-Counties; Samburu North, Samburu Central and Samburu East. Samburu North Sub-County borders Marsabit County to the North and Turkana County to the North West. According to the 2009 Kenya Population and Housing Census, Samburu North Sub-County had a total population of 59,801 spread across 11,699 households, almost equally divided between two administrative units (Baragoi and Nyiro Divisions). . In 2009, Baragoi Division had a total population of 31,043 while Nyiro division had 28,758 people. It covers an area of 7,035.1 Km^2.

Baragoi town is the largest town in Samburu North Sub-County and covers an area of 2.2 Km^2.The town has a population of 4,694, spread across924 households. It is the most densely populated area of Samburu County, with a population density of 2,102 people/Km^2. The main economic activities practiced in the town are livestock farming and small scale trading. .

2.2 Power Demand

The following figure shows the distribution network of Baragoi diesel power plant. In the network there are 5 step down transformers; girl’s high school, boy’s high school, District Commissioner’s residence, hospital and power station. There are also two step down transformers at the town center and at Leilei.



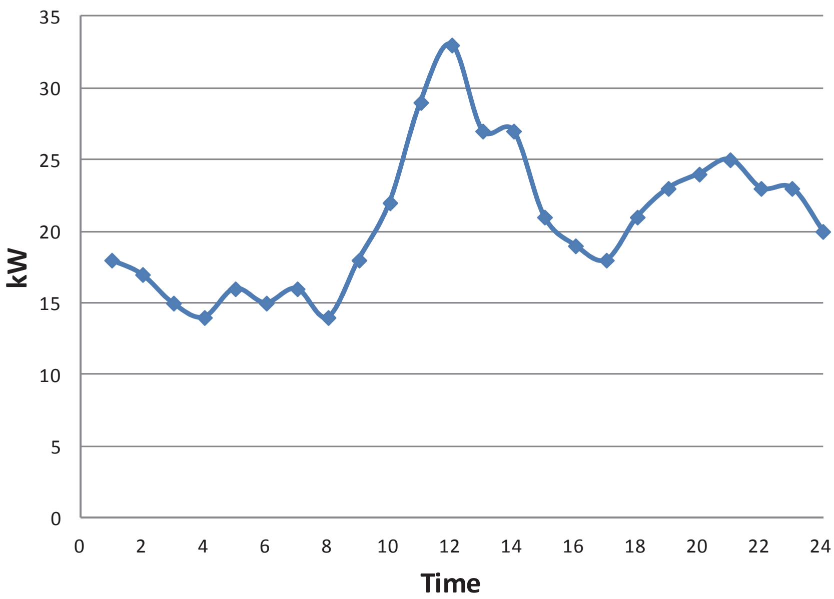
Prepared by JET & REA

Figure 3 Distribution Network (11kVA) in Baragoi

The diesel generator capacity is 300 kVA. It was transferred from Marsabit Diesel Power Station in December 2013, prior to which an 80kVA diesel generator was used to supply power.

At Baragoi diesel power station, the number of O&M staff is ten (10) and the consumption rate of diesel fuel is around 300 to 400 liters per day.

Figure 5 shows the power supply curve of the diesel generator. Diurnal energy output in Baragoi s estimated at around 500 kWh/day.



Time	kW
1	18
2	17
3	15
4	14
5	16
6	15
7	16
8	14
9	18
10	22
11	29
12	33
13	27
14	27
15	21
16	19
17	18
18	21
19	23
20	24
21	25
22	23
23	23
24	20

Prepared by JET & REA

Figure 4 Power Demand Curve (Baragoi, 13th Dec. 2013)

3. WIND ANALYSIS

3.1 Wind Monitoring

Wind monitoring is essential for wind power projects. Wind monitoring and analysis of obtained data are so important for implementation of wind projects. Overestimating wind speed will result in less wind energy being available than expected, which may be disastrous for the economics of the project. Underestimates are less dangerous in the economic sense but may mean that a wind turbine with larger generator should have been installed, possibly saving on the overall cost.

Wind speed and direction vary in the short and the long term. Gusts occur within a matter of seconds. Average wind speeds may change with time of day or the season of the year. The power in the wind is proportional to the cube of the wind speed. It is therefore essential to have detailed analysis of wind characteristics, based on monitored data.

At Baragoi, wind monitoring has been conducted by MoE&P since 8th September 2010. The installed wind monitoring system measures wind speed and direction at 20m and 40m above ground level. Wind speed data is the most important indicator of a site's wind energy resource. Multiple measurement heights are encouraged for determination of a site's wind shear characteristics, conducting turbine performance simulations for several turbine hub heights, and for backup.

The following figure shows the wind monitoring station in Baragoi.

Source: Taken by JET

Figure 5 Wind Monitoring Station in Baragoi

Table 2 shows monthly average wind speed between September 2010 and August 2011. The annual average wind speed at 20 meters above ground level is 4.4 m/s, and that at 40 meters above ground level is 5.3 m/s. On the basis of the summarized monthly wind data, monthly average wind speed is high between December 2010 and April 2011, and low between June and August 2011.

Table 1 Monthly Average / Max Wind Speed

Year	Month	average wind speed (m/s)		max. wind speed (m/s)	
		20m a.g.l.	40m a.g.l.	20m a.g.l.	40m a.g.l.
2010	Sep	4.4	5.1	14.2	14.8
	Oct	4.7	5.6	15.9	17.3
	Nov	3.4	5.1	16.7	17.6
	Dec	5.1	6.0	17.3	20.6
2011	Jan	5.3	6.1	17.4	17.8
	Feb	5.0	5.8	17.2	18.7
	Mar	5.1	6.1	20.1	22.0
	Apr	5.0	6.1	26.2	26.4
	May	4.0	5.0	18.1	20.0
	Jun	3.6	4.2	12.8	14.3
	Jul	3.8	4.4	13.6	14.2
	Aug	3.8	4.4	13.5	15.2
Average		4.4	5.3	16.9	18.2

Prepared by JET & REA

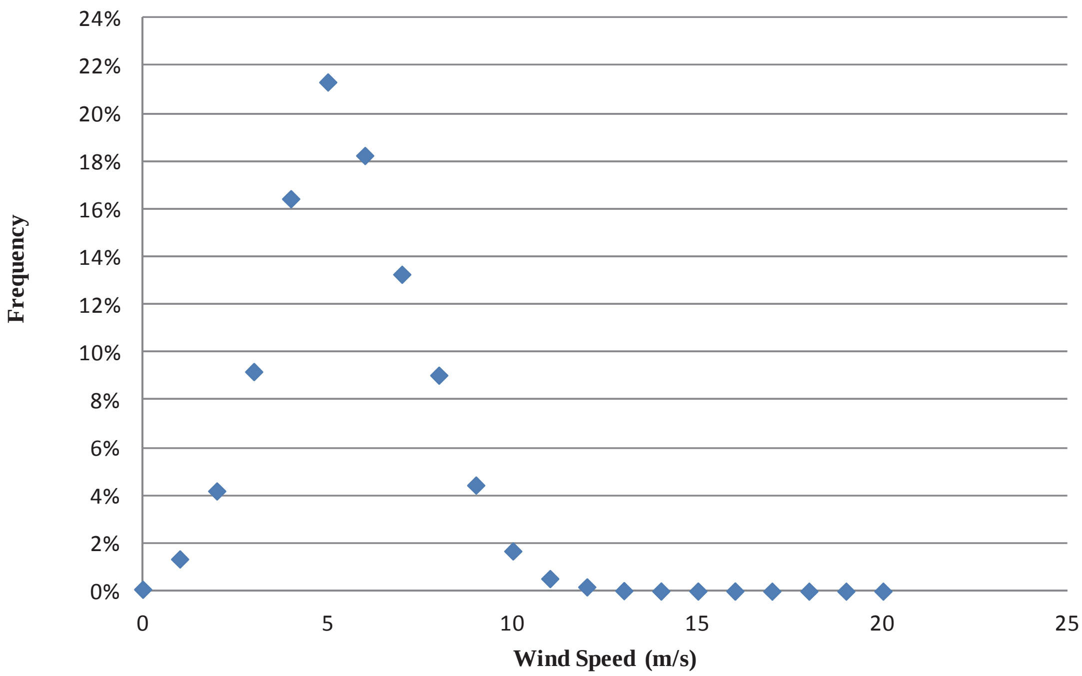
3.2 Data Analysis

Table 2 and Figure 6 show frequency of wind speed at 40 meters above ground level. Over 15% of wind speed frequency was recorded between 4m/s and 6m/s. Around 69% of wind speeds were recorded at 4.5 m/s and higher.

Table 2 Wind Speed Frequency

Wind Class	Range of Wind Speed (m/s)	No. of Data (40m a.g.l)	Frequency (40m a.g.l.)	No. of Data (20m a.g.l)	Frequency (20m a.g.l.)
0	0<V<0.5	37	0.1%	46	0.1%
1	0.5<=V<1.5	641	1.3%	233	0.5%
2	1.5<=V<2.5	1997	4.2%	4352	9.1%
3	2.5<=V<3.5	4376	9.2%	8133	17.1%
4	3.5<=V<4.5	7821	16.4%	11242	23.6%
5	4.5<=V<5.5	10146	21.3%	9448	19.9%
6	5.5<=V<6.5	8682	18.2%	6614	13.9%
7	6.5<=V<7.5	6315	13.3%	4287	9.0%
8	7.5<=V<8.5	4304	9.0%	2172	4.6%
9	8.5<=V<9.5	2114	4.4%	812	1.7%
10	9.5<=V<10.5	801	1.7%	204	0.4%
11	10.5<=V<11.5	251	0.5%	35	0.1%
12	11.5<=V<12.5	85	0.2%	7	0.0%
13	12.5<=V<13.5	10	0.0%	3	0.0%
14	13.5<=V<14.5	3	0.0%	0	0.0%
15	14.5<=V<15.5	2	0.0%	0	0.0%
16	15.5<=V<16.5	3	0.0%	0	0.0%
17	16.5<=V<17.5	0	0.0%	0	0.0%
18	17.5<=V<18.5	0	0.0%	0	0.0%
19	18.5<=V<19.5	0	0.0%	0	0.0%
20	19.5<=V<20.5	0	0.0%	0	0.0%
		47588	100%	47588	100%

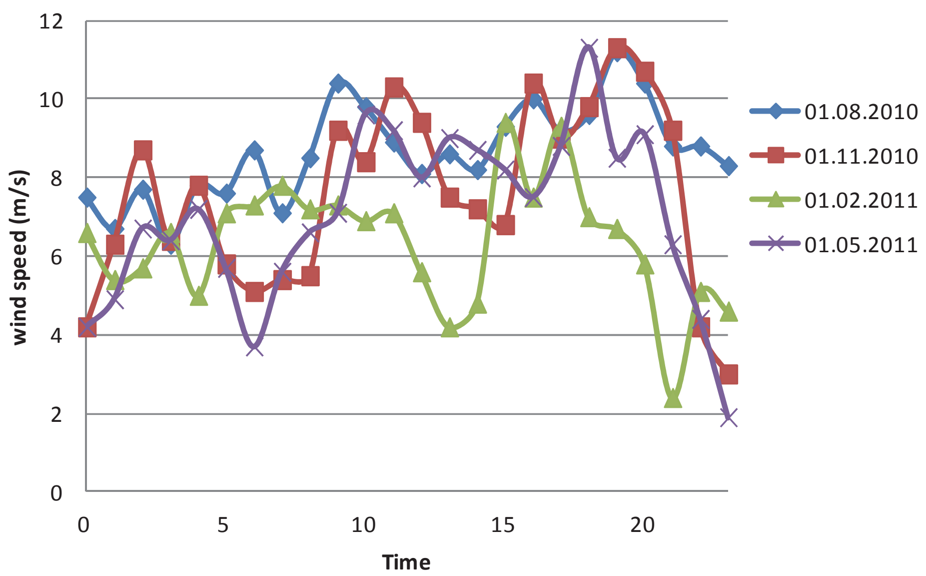
Prepared by JET & REA



Prepared by JET & REA

Figure 6　Wind Speed Frequency

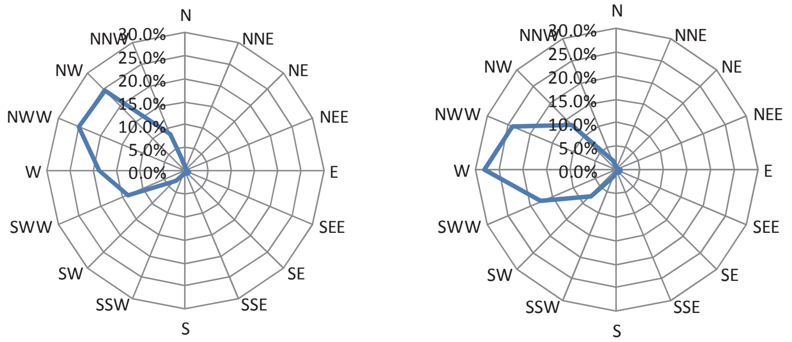
Figure 7 shows diurnal wind speeds in different seasons, 1st of August and 1st of November in 2010, and 1st of February and 1st of May in 2011, at Baragoi. The figure shows that with the exception of February, all the diurnal wind speed patterns show the peak between 19:00 and 20:00.



Prepared by JET & REA

Figure 7　Diurnal Wind Speed

Figure 8 shows wind direction at 40 meters above ground level. Wind direction frequency information is important in identifying preferred terrain shapes and orientations and in optimizing the layout of wind turbines in a wind farm. Prevailing wind directions need to be defined. If the relative frequency of annual wind direction is more than 60% in the wind axis, the wind direction can be considered as stable. Wind axis is defined as the direction of the prevailing wind and the two immediate directions on both sides, and the symmetric directions of these three directions. In total, 6 of the 16 azimuth angles are designated as the wind axis. In the case of Baragoi, more than 70% of wind direction is in the wind axis.



(Left: 40 m above ground level, Right: 20m above ground level)

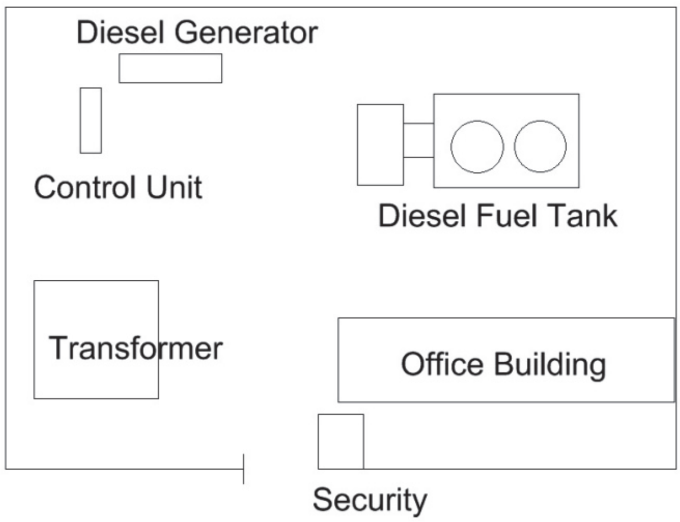
Prepared by JET & REA

Figure 8 Wind Direction

4. PRELIMINARY DESIGN AND COST ESTIMATE

4.1 Baragoi Diesel Power Station

Figure 9 shows simplified layout of Baragoi diesel power station. There are two fuel tanks in the area of power station. The capacity of diesel generator is 300 kVA. Layout of the facility is described in figure 9. The pictures of each facility are shown in figure 10.



Prepared by JET

Figure 9 Layout of Baragoi Diesel Power Station


(Diesel Generator)


(Transformer)


(Control Unit)


(Fuel Tank)

Prepared by JET

Figure 10 Baragoi Diesel Power Station

4.2 Proposed Wind-Diesel Hybrid System

Table 3 shows calculation of power output for a 7.5 kW wind turbine. In the following table, air density was corrected because of the difference between air density under standard conditions and actual values in practice. As for the safety margin, an estimate of 10% was applied in the calculation. In this pre-F/S, hub height for a wind turbine is decided to be 40 meters above ground level which is the same as monitoring height, Therefore, no estimation of wind speed due to height difference between monitoring height and wind turbine is needed.

Table 3 Estimation of Energy Output from Wind

Wind Speed Bin (m/s)	Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.3	0.03	0.03	0.03	0.03	0.05	0.07	0.06	0.06	0.05	0.04	0.02	0.03	0.04
5	0.8	0.16	0.13	0.13	0.14	0.18	0.20	0.21	0.21	0.23	0.18	0.15	0.15	0.17
6	1.7	0.32	0.27	0.27	0.34	0.32	0.21	0.27	0.25	0.31	0.35	0.38	0.33	0.30
7	2.6	0.43	0.41	0.43	0.45	0.33	0.12	0.14	0.18	0.25	0.35	0.51	0.44	0.34
8	3.7	0.46	0.44	0.53	0.47	0.23	0.05	0.07	0.08	0.23	0.34	0.60	0.43	0.33
9	4.9	0.34	0.27	0.47	0.37	0.09	0.01	0.00	0.02	0.12	0.23	0.33	0.29	0.22
10	6.2	0.19	0.23	0.19	0.19	0.01	0.00	0.00	0.00	0.02	0.10	0.15	0.14	0.10
11	7.5	0.07	0.10	0.06	0.07	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.04
12	8.0	0.04	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.01
13	8.0	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	7.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	2.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		2.05	1.92	2.13	2.07	1.21	0.66	0.75	0.80	1.22	1.61	2.22	1.95	1.56

Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Net kW	2.05	1.92	2.13	2.07	1.21	0.66	0.75	0.80	1.22	1.61	2.22	1.95	1.56
kW	1.58	1.48	1.64	1.59	0.93	0.51	0.58	0.61	0.94	1.24	1.71	1.50	1.20
Daily (kWh/day)	37.9	35.6	39.4	38.3	22.3	12.2	13.9	14.7	22.5	29.8	41.1	36.1	28.8
Monthly(kWh/Mo)	1,173	997	1,220	1,148	691	366	432	457	674	923	1,232	1,118	10,512

Air density (monitored)	1.05
Air density (std.)	1.226
Air density Ratio	86%
Safety Margin	10%

Prepared by JET & REA

Capacity Factor = 1.2 / 7.5 = 16.0%

4.3 Selection of Wind Turbine

In this pre-F/S, low wind penetration system can be recommended for Baragoi Diesel station to accumulate experience of operating a Wind-Diesel Hybrid system. Therefore, target annual energy penetration should be less than 15%.

$$\text{Annual Energy Penetration (\%)} = \frac{\text{Annual Wind Energy Output (kWh)}}{\text{Annual Primary Energy Demand (kWh)}} \times 100(\%)$$

Here, Annual Primary Energy Demand can be estimated as follows;

Annual Primary Energy Demand = 500 kWh/day × 365 (day/year)
= 182,500 kWh/year

Therefore, target of annual wind energy output becomes;

Annual Wind Energy Output (kWh) =

AnnualEnergy Penetration (%) × AnnualPrimary Energy Demand (kWh) = 0.15 ×182,500
= 27,375 (kWh/year)

Number of wind turbines are decided as follows;

Annual Wind Energy Output ÷ Estimated Energy Output of a Turbine = 27,375 / 10,512
= 2.60

Therefore, the penetration ratio can be designed to be less than 15% by installing two wind turbines of 7.5 kW.

Annual Energy Penetration = 10,512 ×2 / 182,500 = 11.52 %

Therefore, in this simple pre-F/S, three wind turbines with a total capacity of 15.0 kW was selected.

4.4 Cost Estimate

The cost of wind turbine installation and transportation to project site depend on the contractor and selected project site. The table below shows sample costs for the wind turbine installation.

Table 4 Costs for Wind Turbine Installation

	Unit	Unit Cost (USD)	Units	Cost(USD)	Cost (kSh)
Wind Turbine	kW	5,000	15	75,000	6,600,000
Inverter	kVA	700	15	10,500	924,000
Battery	kAh	3,600	4	14,400	1,267,200
Control House	(1/system)	2,000	1	2,000	176,000
Installation Materials	kW	600	15	9,000	792,000
Installation Work	kW	500	15	7,500	660,000
Transportation	kg	3	1,000	3,000	264,000
Total Investment Cost	-	-	-	121,400	10,683,200

Prepared by JET & REA

4.5 Construction Schedule

Installation of small scale wind turbines can be completed within a short period. However the following should be considered when preparing a schedule for installation.

- Procurement and shipping schedule of necessary equipment
- Transportation to the Project Site
- Season in which installation will be done (avoid rainy seasons)
- Curing period of foundation
- Installation period of tower and turbine
- Wiring of building
- Connection to diesel mini-grid
- Commissioning

Table 5 shows a sample installation schedule for wind turbine. The details of the schedule have to be determined in conjunction with the installer.

Table 5 Installation Schedule

N	Schdule of Wind Turbine Construction		1st Week			2nd Week			3rd Month		
1	Civil Works	Land Preparation									
		Construction of Basement									
		Maintains the area of the generating plant									
2	Electrical Works	Wireing for interconnection									
		Installation of switchboard and the cubicle									
		Wiring and Grounding Works									
3	Wind Turbine (including transportation)	Assembly and Installation of Tower									
		Assembly and Installation of nacell and rotor									
		Installation and the wiring of the control unit									
4	Comissioning Test	Examination by Manufacture (adjustment)									
		Self-imposed test									
		Testing Operation									

Prepared by JET & REA

5. OPERATION AND MAINTENANCE

5.1 Implementation Organization

Maintenance inspection is essential to maintain a high operating rate of the wind turbine generator. For O&M, daily monitoring of operation, periodic and irregular maintenance and modification and the repair of equipment are required. Monitoring of operation with daily inspection contributes to detection of deficiencies early. For wind turbines, it is necessary to have an agreement on O&M with manufactures and/or suppliers. It is necessary to maintain a high operating rate of the wind turbine, so that rehabilitation is conducted promptly after the maintenance works. Aspects of O&M which have to be discussed with manufacture and/or suppliers are written in the "Guideline for Wind Power" Chapter 5 Operation & Maintenance.

5.2 Operation and Maintenance

The wind turbine generator has many mechanical parts, and periodic inspections such as refilling of the lubricating oil or replacement of consumable supplies are required.

The company in charge of O&M and REA, MoE&P or Owner Company have to enter into a joint and binding maintenance agreement to improve the operating rate so that mechanical and electrical inspections can be carried out. The periodic inspection varies according to manufactures but carrying out four inspections per year is recommended by manufactures in general. Therefore, REA and/or MoE&P can include periodic inspection in tender documents.

For inspection of contents, visual inspection will be conducted for cable, blade and tower booms. Moreover, lubricating oil refilling, terminal strapping, bolt dip, and braking system will be inspected. It is necessary to change the oil in braking valve unit, gear box and oil hydraulic brakes regularly. Items for periodical inspection were summarized in the "Guideline for Wind Power" Chapter 5 Operation & Maintenance.

6. PROJECT JUSTIFICATION

The cost of installing a wind turbine is simply the cost of the wind turbine, tower, wiring installation and taxes and so on. Maintenance costs are expenses incurred in servicing or repairing the wind system. According to "Wind Power", the vast amount of experience from commercial wind turbines indicates that the cost of operating and maintaining small and medium size turbines is about 1 cent per kilowatt-hour in U.S.A.

One of the advantages of wind energy over electricity generated by conventional means is the free fuel. Once wind turbines are installed, the energy produced costs little over the remaining life of the wind turbines. The table below shows a sample of benefit from the installation of a 15kW wind turbine. The benefit is equivalent to the diesel cost replaced by power supplied from the wind turbine.

6.1 Economic and Financial Evaluation

The cost of installing a wind turbine is simply the cost of the wind turbine, tower, wiring installation, taxes and so on. Maintenance costs are expenses incurred in servicing or repairing the wind system.

One of the advantages of wind energy over electricity generated by conventional means is the free fuel. Once wind turbines are installed, the energy produced costs little over the remaining life of the wind turbines. The table below shows a sample of benefit from the installation of a 15kW wind turbine. The benefit is equivalent to the diesel cost replaced by power supplied from the wind turbine.

Table 6 Benefit from wind turbine installation

Generation capacity of the wind turbine	15	kW
Capacity factor (Wind)	16.0%	
Operation hour per day	24	Hours
Operation day per year	360	days
Annual power generation (Wind)	20,736	kWh/Y
Life time of the wind turbine	20	Years
OM cost of the generation system (% of the investment)	2.0%	
Diesel fuel cost per litter	105.0	kSh/litter
Fuel consumption	0.67	litter/kWh
Fuel cost per kWh	70.35	kSh/kWh

Benefit (Replaced Diesel Cost) 1,458,778 kSh/Y

Prepared by JET & REA

Table 7 shows EIRR of installation of wind turbines at an existing diesel power plant. The cost of rehabilitating the existing diesel power plant is not included. According to the Central Bank of Kenya the discount rate in Kenya was 7% on 31st December 2010. In April 2014, The World Bank released its Commodity Forecast, which predicts that world crude oil price will decrease from $104/barr. in 2013 to $97/barr. by 2020. In the table, the fuel price escalation rate is estimated at 2% for a period of 20 years.

Table 7 EIRR wind turbine installation

Year	Benefit	Cost						Cumulatuve
	saved fuel cost (kSh)	Initial investmen	O&M	Battery	Inverter	Controller	TOTAL	Revenue
0		-10,683,200					-10,683,200	-10683200
1	1,458,778		-132,000				-132,000	1,326,778
2	1,487,953		-134,640				-134,640	1,353,313
3	1,517,712		-137,333				-137,333	1,380,379
4	1,548,066		-140,079				-140,079	1,407,987
5	1,579,028		-142,881				-142,881	1,436,147
6	1,610,608		-145,739	-1,267,200			-1,412,939	197,670
7	1,642,821		-148,653				-148,653	1,494,167
8	1,675,677		-151,627		-924,000	-330,000	-1,405,627	270,050
9	1,709,190		-154,659				-154,659	1,554,531
10	1,743,374		-157,752				-157,752	1,585,622
11	1,778,242		-160,907				-160,907	1,617,334
12	1,813,807		-164,125	-1,267,200			-1,431,325	382,481
13	1,850,083		-167,408				-167,408	1,682,675
14	1,887,084		-170,756				-170,756	1,716,328
15	1,924,826		-174,171				-174,171	1,750,655
16	1,963,323		-177,655		-924,000	-330,000	-1,431,655	531,668
17	2,002,589		-181,208				-181,208	1,821,381
18	2,042,641		-184,832	-1,267,200			-1,452,032	590,609
19	2,083,494		-188,529				-188,529	1,894,965
20	2,125,164		-192,299				-192,299	1,932,864
	35,444,459		-3,207,253	-3,801,600	-1,848,000	-660,000	-20,200,053	15,244,406

EIRR	10.0%
NPV	2,726,206

Project life	20	Years		
Number of Target Households	150	HHs	Fuel Price Escalation Rate	2%
Exchange rate (as of 6 June, 2014)	102.0 Yen/US$		Discount Rate	7% (31 Dec. 2010, Central Bank)

Prepared by JET & REA

In wind projects, the value of EIRR becomes higher with increase of capacity factor of a wind turbine. The capacity factor increases in proportion to increase of average wind speed. The table below shows relation between capacity factor and EIRR of the simple pre-F/S.

Table 8 Capacity Factor vs. EIRR

Capacity Factor	EIRR
15%	8.8%
20%	14.5%
25%	19.6%

Prepared by JET & REA

6.2 Environment

Environmental procedures have to be undertaken in accordance with the “Guideline for Wind Power” prepared by REA and JET.

WIND DATA ANALYSIS

Tsutomu DEI (JET)
Hannington Gochi (REA)

JICA / REA PROJECT

PROJECT FOR ESTABLISHMENT OF RURAL ELECTRIFICATION MODEL USING RENEWABLE ENERGY

- **Overall Goal:**
  Rural electrification models using renewable energy are disseminated in the country to improve the quality of Kenyan's life.
- **Project Purpose**:
  Rural electrification models using renewable energy are established

PROJECT OUTPUTS

(1) A practical model for electrification of health service institutions in non-electrified areas using solar PV is developed through pilot projects.
(2) A practical model for electrification of schools in non-electrified areas using Solar PV is developed through pilot projects.
(2) The capacity of REA and MoEn to undertake projects using micro hydropower, biogas and wind technologies is enhanced.
(3) Necessary policy and institutional frameworks for spreading the models for rural electrification using renewable energy are recommended.

Pilot Solar PV

Other Renewables (Wind, MHP, Biogas)

- Technical Transfer
  - Conduct inventory and review of existing studies
  - Prepare guidelines for rural electrification using renewable
  - Conduct technical training for REA / MoE&P staff
  - Carry out simple pre-feasibility study
  - Prepare technical recommendation for rural electrification

Wind Energy in Kenya

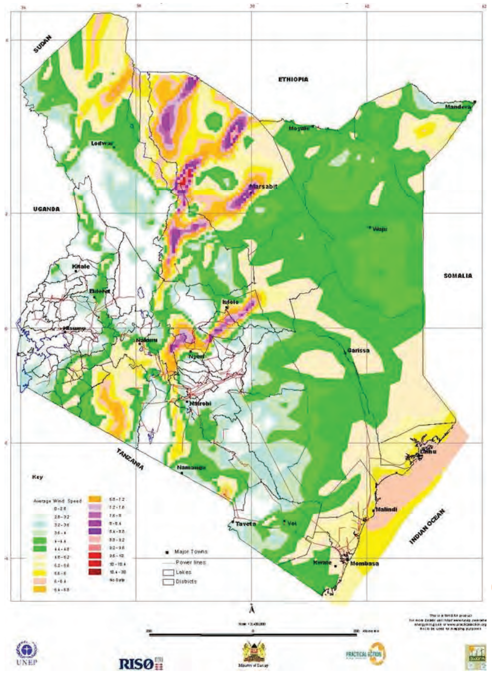
- Wind Development in Kenya
- Wind Potential in Habaswein
- Operational Data at Habaswein Diesel Hybrid Power Station

Mr. Hannington Gochi

Renewable Energy Department
Rural Electrification Authority

Wind Development in Kenya

Wind Potential Map in Kenya



(50m a.g.l)

Installed Wind

- Grid Connected: 5.1 MW (Ngong Hills-KenGen)
- Diesel Hybrid: 560 kW (Marsabit & Habaswein -KPLC)
- Stand Alone: 460 kW (Mainly from Telecommunication sites across the country)

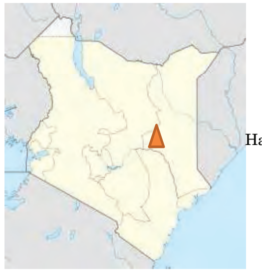
Grid-connected (Ngong Hills)

Stand Alone (Oloshoibor Communituy Center : Kajiado)

UNIDO Project:
PV 2kW
Wind 3kW
SVO 9kW

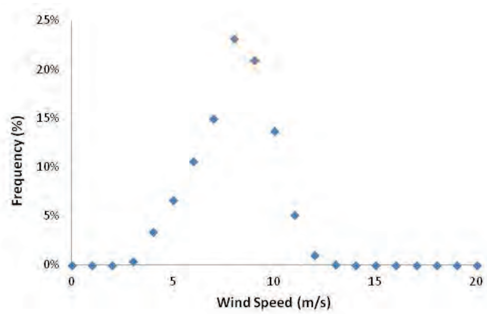
Wind Potential in Habaswein

Habaswein Diesel Power Station



Wind Monitoring Station at Habaswein

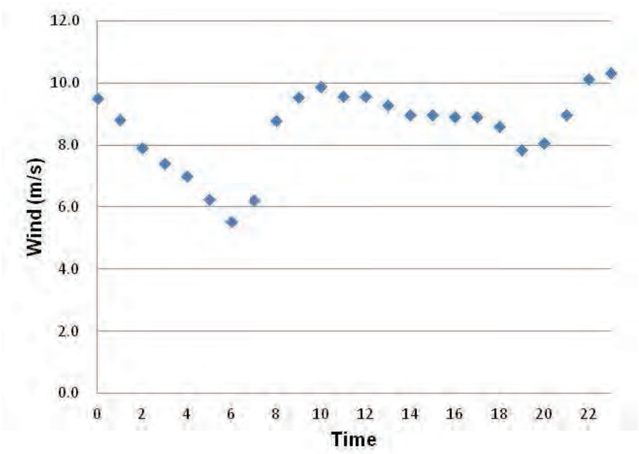
Frequency of wind speed (%)



Wind Class	Range of Wind Speed (m/s)	No. of Data (20m)	Frequency (%)(20m)
0	0<V<0.5	0	0.0%
1	0.5<=V<1.5	0	0.0%
2	1.5<=V<2.5	0	0.0%
3	2.5<=V<3.5	16	0.4%
4	3.5<=V<4.5	149	3.4%
5	4.5<=V<5.5	292	6.7%
6	5.5<=V<6.5	466	10.6%
7	6.5<=V<7.5	657	15.0%
8	7.5<=V<8.5	1015	23.1%
9	8.5<=V<9.5	918	20.9%
10	9.5<=V<10.5	600	13.7%
11	10.5<=V<11.5	224	5.1%
12	11.5<=V<12.5	46	1.0%
13	12.5<=V<13.5	4	0.1%
14	13.5<=V<14.5	0	0.0%
15	14.5<=V<15.5	0	0.0%
16	15.5<=V<16.5	0	0.0%
17	16.5<=V<17.5	0	0.0%
18	17.5<=V<18.5	0	0.0%
19	18.5<=V<19.5	0	0.0%
20	19.5<=V<20.5	0	0.0%
		4387	100.0%

(August, 2011)

Diurnal Wind Speed



(20m a.g.l, August, 2011)

Time	(m/s)
0	9.5
1	8.8
2	7.9
3	7.4
4	7.0
5	6.2
6	5.5
7	6.2
8	8.8
9	9.5
10	9.9
11	9.6
12	9.6
13	9.3
14	9.0
15	9.0
16	8.9
17	8.9
18	8.6
19	7.8
20	8.1
21	9.0
22	10.1
23	10.3
Average	8.5

Estimated Power Output

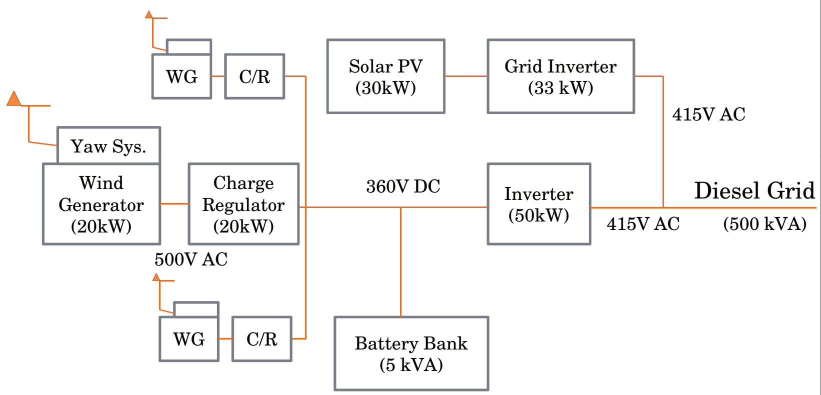
Wind (m/s)	Power Output (kW)	Wind Speed Frequency	Net kW (kW)
0	0	0	0
1	0	0	0
2	0	0	0
3	0.55	0.00	0
4	1.15	0.03	0.04
5	1.65	0.07	0.11
6	2.35	0.11	0.25
7	3.36	0.15	0.50
8	4.80	0.23	1.11
9	6.86	0.21	1.44
10	9.80	0.14	1.34
11	14.00	0.05	0.71
12	20.00	0.01	0.21
13	25.43	0.00	0.02
14	25.43	0	0
15	25.43	0	0
16	25.43	0	0
17	25.43	0	0
18	25.43	0	0
19	25.43	0	0
20	25.43	0	0

Total Net kW	5.74	kW
Net kW (include loss)	4.60	kW
Rated Power Output:	20	kW
Capacity Factor	23.0%	
Estimated Daily Output	110.3	kWh/day

Operational Data at Habaswein Diesel Hybrid Power Station

Wind-PV-Diesel Hybrid Power Generation System

Block diagram of the system



System Configuration

ITEM	RATING
Wind Generator	20 kW
Charge Regulator Brake System & Yaw System	20 kW
Inverter	50 kVA
Battery Charger	20 kW

Wind Turbine GE-200

TECHICAL CHARACTERISTICS

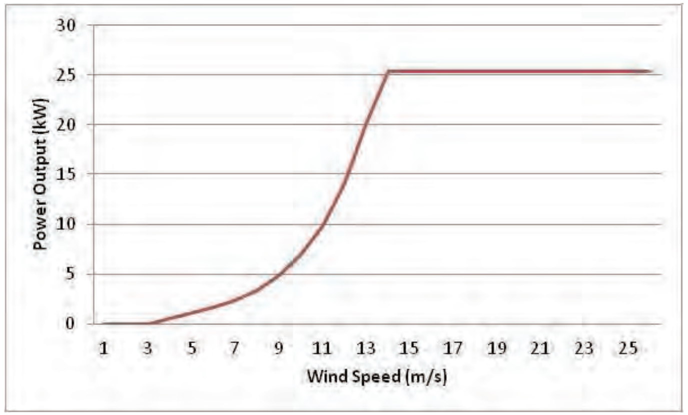
Model	-	GCE-200
Rated power of WTG	-	20 kW
Max Power output	-	25.5 kW
Output Voltage	-	360 Vac
Generator	-	Permanent Magnet
Number of blades	-	3
Material of blades	-	Fibre glass
Rotor diameter	-	10m

TECHICAL CHARACTERISTICS

(WTG) CONT'D…..

Rated Wind Speed	-	12m/s
Cut-in Wind speed	-	3m/s
Cut-out Wind speed	-	20m/s
Rated speed	-	90 rpm
Tower height	-	18m
Weight	-	400kg

PERFORMANCE OF WIND TURBINE GE-200



Wind (m/s)	Output (kW)
0	0
1	0.0
2	0.0
3	0.6
4	1.2
5	1.7
6	2.4
7	3.4
8	4.8
9	6.9
10	9.8
11	14.0
12	20.0
13	25.4
14	25.4
15	25.4
16	25.4
17	25.4
18	25.4
19	25.4
20	25.4
21	25.4
22	25.4
23	25.4
24	25.4
25	25.4

CHARGE REGULATOR RF 200

TECHNICAL CHARACTERISTICS

Model - RF 200
Rated Power - 20 kW

Input
Phases - 3
Voltage - 0-500 Vac
Frequency - 0-30 Hz

TECHNICAL CHARACTERISTICS

(CHARGE REGULATOR) CONT'D….

Output
Voltage - 360Vdc + 12%
Efficiency - 99%

Signals
LED - On, charge, Fault
Manual switch - Emergency brake
Emergency Power Off - Charge Regulator

TECHNICAL CHARACTERISTICS
(CHARGE REGULATOR) CONT'D….

Environmental

Temperature	-	-22°C - 50°C
Non-condensing humidity	-	0%-90%
Noise (at 1m)	-	< 50dBA
Cooling	-	Forced

INVERTER
GCI-814.360

TECHNICAL CHARACTERISTICS

Model	-	GCI-814.360
Rated power	-	50 kW
Input		
Voltage	-	360 Vdc ± 20%
Output		
Wave-form	-	PURE SINE WAVE
Harmonic Distortion	-	< 2%
Phases	-	Three + N

TECHNICAL CHARACTERISTICS
(INVERTER) CONT'D…..

Voltage	-	415 Vac ± 1%
Frequency	-	50Hz ± 0.05%

Environmental

Operating Temperature	- 0° C – 50° C
Non-condensing Humidity	- 0% - 90%
Noise (at 1m)	- < 50 dBA

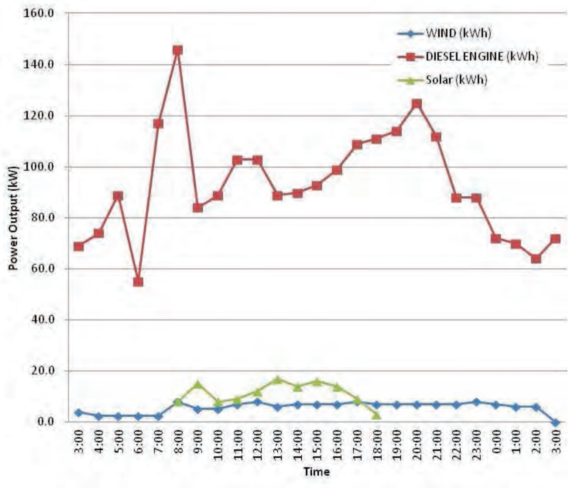
Solar PV

Diesel Generator

Battery Bank

Transformer

OPERATIONAL DATA (1)



(May, 4th – 5th, 2013)

OPERATIONAL DATA (2)

Date	TIME	WIND (kWh)	DIESEL (kWh)	SOLAR (kWh)
2013/5/4	3:00	4.0	69	0
	4:00	2.5	74	0
	5:00	2.5	89	0
	6:00	2.5	55	0
	7:00	2.5	117	0
	8:00	8.0	146	8
	9:00	5.0	84	15
	10:00	5.0	89	8
	11:00	7.0	103	9
	12:00	8.0	103	12
	13:00	6.0	89	17
	14:00	7.0	90	14
	15:00	7.0	93	16
	16:00	7.0	99	14
	17:00	8.0	109	9
	18:00	7.0	111	3
	19:00	7.0	114	0
	20:00	7.0	125	0
	21:00	7.0	112	0
	22:00	7.0	88	0
	23:00	8.0	88	0
2013/5/5	0:00	7.0	72	0
	1:00	6.0	70	0
	2:00	6.0	64	0
Total Output (kWh/day)		144	2,253	125

Capacity Factor:

Wind	**15.0%**
Solar PV	**17.4%**

CONCLUSION

- In August 2011, monthly average wind speed is high as 8.5 m/s at 20 meters above ground level in Habaswein.
- In the period, wind speed is recorded over 9.0 m/s between 21:00 to 24:00 when solar radiation is not available.

RECOMMENDATIONS

- Operational condition have to be monitored with data logger.
- It is apparent that most parts in Kenya (for example Marsabit, Garissa, Coast, etc) have good wind speed capable of generating large a mounts wind power. Harnessing of Wind energy for various applications is therefore one sure way of achieving in power sustainability, environmental sustainability and poverty reduction among others.

Pre-Feasibility Study on Wind-Diesel Hybrid System in Baragoi

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Abstract:
This paper shows the results of simple pre-feasibility study on wind - diesel hybrid power generation system at Baragoi, Samburu County in Kenya. At Baraboi, wind speed and direction are being monitored at 20 meters and 40 meters above ground level respectively by Ministry of Energy and Petroleum (MOE&P). In this study, power output from a wind turbine is estimated based on the monitored wind data.
There is an autonomous diesel power station in Baragoi which supplies electricity to customers in the area. Power output from the diesel generator was obtained and analyzed.
The collected data enabled estimation of potential power output from wind turbine. In addition, the conceptual design of hybrid system with existing diesel power station was studied.

1.0 Introduction

The purpose of this pre feasibility study is to evaluate the wind potential at Baragoi in Samburu County and conceptual design for wind and diesel hybrid system. Baragoi is located in Samburu County, and the population of entire Baragoi is **31,043 (2009 census)** comprising mostly people from the Samburu and Turkana tribes.
Wind and diesel power plant can be used in combination for power supply of autonomous system where a connection to the national grid is either impossible or too expensive due to long transmission line. The diesel generators provide power when needed, whereas the wind turbines act to reduce the diesel fuel consumption. The most important purpose of wind and diesel hybrid system is to reduce the consumption of diesel oil. In general, isolated diesel power stations are located in remote areas. Therefore, transportation and oil storage cost can be reduced.
As the most important critical design factor, wind penetration need to be considered.
Wind penetration shows how much energy is coming from the wind and it is useful to

determine the level of system complexity. Table 1 shows three different types of wind penetrations.

Table 1 Wind Penetration

Penetration Class	Operating Characteristics	Peak Instantaneous Penetration	Annual Average Penetration
LOW	• Diesel runs full-time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
MEDIUM	• Diesel runs full-time • At high wind power levels, secondary loads are dispatched to ensure sufficient diesel loading or wind generation is curtailed • Requires relatively simple control system	50%–100%	20%–50%
HIGH	• Diesels may be shut down during high wind availability • Auxiliary components are required to regulate voltage and frequency • Requires sophisticated control system	100%–400%	50%–150%

(Source: Wind Energy: Renewable Energy and Environment, Second Edition)

The frequency of a power system is determined by the balance between input power from the generators and the power taken from the load. If the generator output exceeds the load, surplus power will act to increase the rotational speed of the generators and hence the system frequency. Conversely, if the load demand exceeds the power available from the generator, the frequency will fall. In diesel mini-grid, it is necessary to supply consumers with electricity at a controlled voltage and frequency in the same way with national grid. In a wind-diesel system, any surplus power will produce a rapid rise in the rotational speed of the generators and system frequency. The control of the frequency in a wind-diesel system is likely to be difficult and expensive, even though it may achieve significant savings in diesel fuel consumption. It is possible to consider the system with batteries, flywheel and other devices. However, the storage adds considerable expenses and complexity to any wind-diesel system.

In this pre-F/S, a low wind penetration system was designed for Baragoi Diesel station due to the very little control or integration of wind turbines into the power system needed. In addition, low penetration system is effective to accumulate experience of operation of Wind-Diesel Hybrid system. In this paper, the following are studied.

(1) Wind profile

(2) Diesel mini-grid

(3) Low wind penetration

2.0 Materials and Methods

2.1 Wind Profile

In Baragoi, wind monitoring has been carried out by MoE&P since September 2010. A wind monitoring system with a 40 meters height of tower was installed. Anemometers and wind vanes were attached at 20m and 40m above ground level respectively. Figure 1 shows the wind monitoring station in Baragoi.

Figure 1 Wind Monitoring Station in Baragoi

Table 2 shows monthly average wind speed between September 2010 and August 2011. The annual average wind speed at 20 meters above ground level is recorded at 4.4 m/s, and that of 40 meters above ground level is 5.3 m/s. The monthly wind speed is high between December 2010 and April 2011, and the monthly average is low between June and August 2011.

Table 2 Average Monthly Wind Speed (m/s)

Year	Month	average		max	
		20m	40m	20m	40m
2010	9	4.4	5.1	14.2	14.8
	10	4.7	5.6	15.9	17.3
	11	3.4	5.1	16.7	17.6
	12	5.1	6.0	17.3	20.6
2011	1	5.3	6.1	17.4	17.8
	2	5.0	5.8	17.2	18.7
	3	5.1	6.1	20.1	22
	4	5.0	6.1	26.2	26.4
	5	4.0	5.0	18.1	20
	6	3.6	4.2	12.8	14.3
	7	3.8	4.4	13.6	14.2
	8	3.8	4.4	13.5	15.2
Average		4.4	5.3	16.9	18.2

Figure 2 shows diurnal wind speed in different seasons, 1st of August, 1st of November in 2010 and 1st of February and 1st of May in 2011. Except the diurnal data of February, diurnal wind speed pattern shows the peak between 19:00 and 20:00.

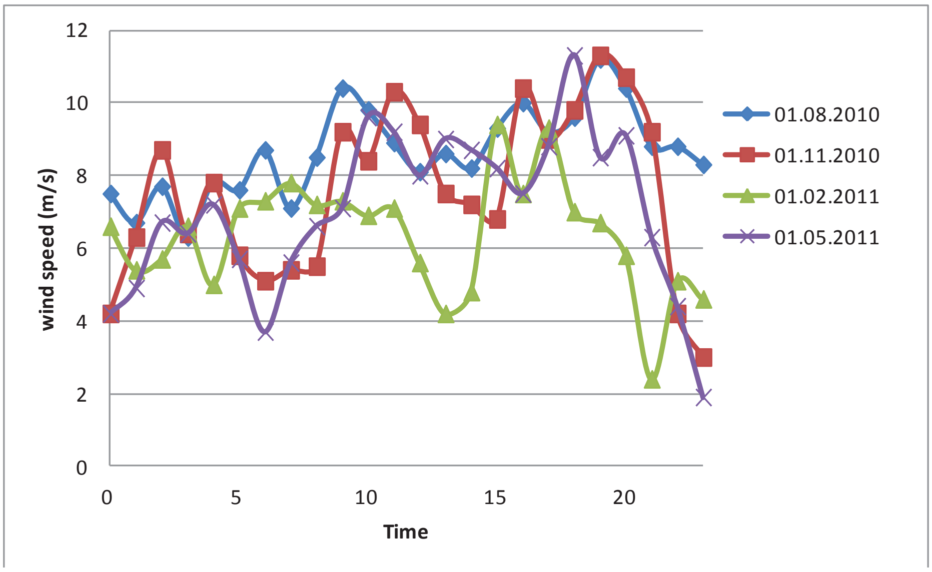

Figure 2 Diurnal Wind Speed

Figure 3 shows frequency of wind speed at 40 meters above ground level. Over 15% of wind speed frequency was recorded between 4m/s and 6m/s. Around 69% of wind speeds are recorded at 4.5 m/s and above.

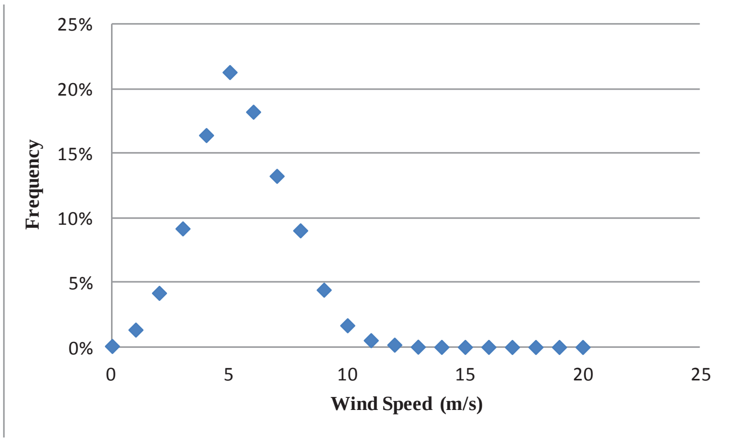

Figure 3 Frequency of Wind Speed

Figure 4 shows wind direction at 40 meters above ground level. Wind direction frequency information is important in identifying preferred terrain shapes and orientations and in optimizing the layout of wind turbines in a wind farm. Prevailing wind directions need to be defined. If the relative frequency of annual wind direction is more than 60% in the wind axis, the wind direction can be considered as stable. Wind axis is defined as the direction of the prevailing wind and the two immediate directions on both sides, and the symmetric directions of these three directions. In total, 6 azimuths out of the 16 azimuth angles are designated as the wind axis. In the case of Baragoi, more than 70% of wind direction is in the wind axis.

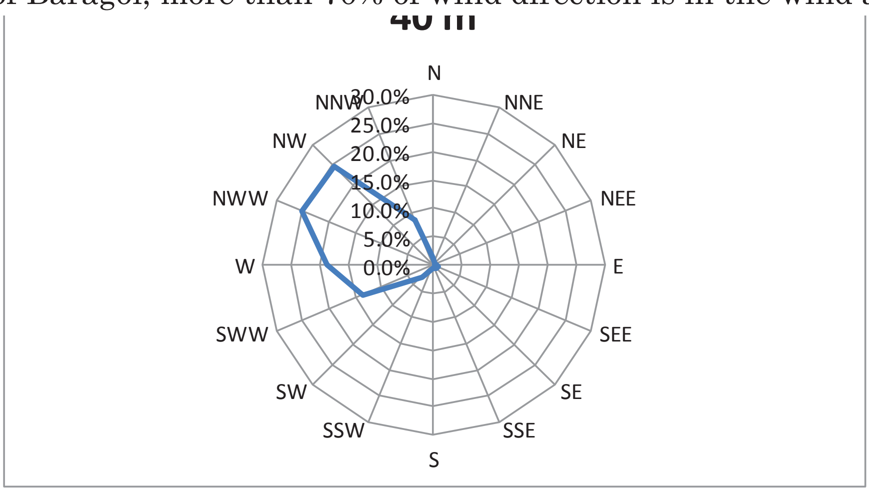

Figure 4 Wind Direction (40m)

2.2 Diesel Mini-grid

Capacity of diesel generator is 300 kVA which was transferred from Marsabit Diesel Power Station in December 2013. At the Baragoi diesel power station, the number of O&M staff is ten (10). Diesel consumption rate is around 300 to 400 liters per day. Figure 5 shows demand curve of the diesel generator. Diurnal energy output can be estimated around 500 kWh/day in Baragoi.

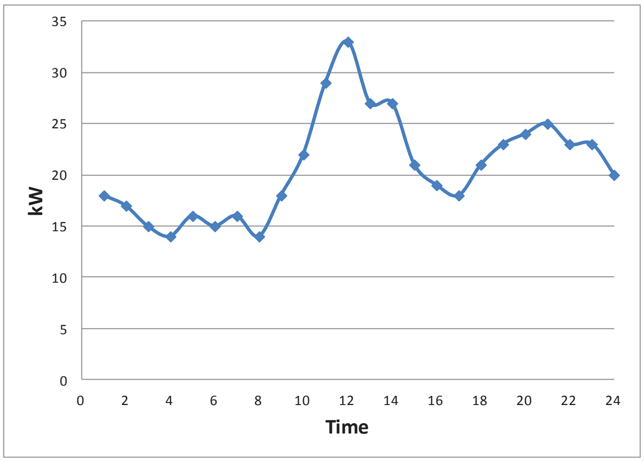

Figure 5 Demand of Diesel Generator

2.3 Low Wind Penetration System

Among the issues of integrating a wind turbine into existing diesel generator are voltage and frequency control, frequent stops and starts of the diesel, utilization of surplus energy, and the use and operation of new technology. These issues vary with penetration values. Wind penetration is a common measure value of performance for wind diesel systems which shows the ratio between Wind Power and Total Power delivered. For example, 30% wind penetration implies that 30% of the system power comes from the wind. Wind penetration figures can be either peak or long term figures. The ratio is a key factor to decide specification of the project especially in determining necessity of stabilizer.

The low wind penetration system is the simplest and easiest wind-diesel hybrid system for construction and operation. There is no secondary load controller, no energy storage such as battery bank, and no modification of existing diesel generator. However, compared to the higher wind penetration system, avoided diesel fuel consumption is minimal. One significant advantage of a low wind penetration approach is that it allows the operating company to gain experience with wind-diesel operation before potentially expanding the system to higher wind penetration. In this pre-F/S, target annual energy penetration was decided to be less than 20%.

The following is necessary information and calculations for the basic design of low wind penetration system.

1) Study the operational record of existing diesel generator and calculate the following information.

- Annual Energy Output (kWh/year)
- Monthly Energy Output (kWh/month)
- Diurnal Energy Output (kWh/day)

2) Estimate power output of the candidate wind turbine to calculate the following information.

- Annual Energy Output (kWh/year)
- Monthly Energy Output (kWh/month)
- Diurnal Energy Output (kWh/day)

3) Calculate average penetration

$$\text{Annual Energy Penetration} = \frac{\text{Annual Wind Energy Output (kWh)}}{\text{Annual Primary Energy Demand (kWh)}} \times 100(\%)$$

2.4 Estimation of Power Output

The amount of energy in wind is a function of its speed and mass. At higher wind speed, more energy is available. Wind energy is the rate at which energy is available, or the rate at which energy passes through an area per unit time. The following formula shows the power that can be generated from wind.

$$P = \frac{1}{2}\rho A V^3$$

P: wind power (W)

ρ : Air density (kg/m^3)

A: Swept area (m^2)

V: Wind velocity (m/s)

3.0 Results

3.1 Wind Penetration

An appropriate wind capacity to meet with low wind penetration was calculated as shown below. In this simple-pre-F/S, target wind penetration is decided around 15% to avoid any expensive modification of existing diesel generator.

Annual Wind Energy Output	=	WG (kW) × 0.2 × 8760 (hr/year) (0.2 = Capacity Factor)
	=	WG (kW) × 1752
Annual Primary Energy Demand	=	500 (kWh/day) × 365 (day/year)

= 182,500 kWh/year

WG (kW) for 15% wind penetration becomes as follows;

WG (kW) = 0.15×182,500 / 1752 = 15.63

Therefore, in this pre-F/S, total capacity of wind turbine should be around 15 kW.

Instantaneous penetration ratio was not calculated for pre-F/S. This is because the capacity of the currently installed diesel generator is 300 kVA, however, the peak of the power demand is as small as around 33 kW. The capacity of diesel generator was 80 kVA before December 2013, and that capacity was more suitable for the current power demand of Baragoi.

3.2 Estimation of Energy Output

Table 3 shows calculation of power output from a 7.5 kW wind turbine. In the following table, air density was corrected because there is difference between air density in standard condition and that of actual. As for safety margin, 10% was estimated in the calculation.

Table 3 Estimated Monthly Power Output

Net kW 7.5kW

Wind Speed Bin (m/s)	Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.3	0.03	0.03	0.03	0.03	0.05	0.07	0.06	0.06	0.05	0.04	0.02	0.03	0.04
5	0.8	0.16	0.13	0.13	0.14	0.18	0.20	0.21	0.21	0.23	0.18	0.15	0.15	0.17
6	1.7	0.32	0.27	0.27	0.34	0.32	0.21	0.27	0.25	0.31	0.35	0.38	0.33	0.30
7	2.6	0.43	0.41	0.43	0.45	0.33	0.12	0.14	0.18	0.25	0.35	0.51	0.44	0.34
8	3.7	0.46	0.44	0.53	0.47	0.23	0.05	0.07	0.08	0.23	0.34	0.60	0.43	0.33
9	4.9	0.34	0.27	0.47	0.37	0.09	0.01	0.00	0.02	0.12	0.23	0.33	0.29	0.22
10	6.2	0.19	0.23	0.19	0.19	0.01	0.00	0.00	0.00	0.02	0.10	0.15	0.14	0.10
11	7.5	0.07	0.10	0.06	0.07	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.04
12	8.0	0.04	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.01
13	8.0	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	7.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	2.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		2.05	1.92	2.13	2.07	1.21	0.66	0.75	0.80	1.22	1.61	2.22	1.95	1.56

Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Net kW	2.05	1.92	2.13	2.07	1.21	0.66	0.75	0.80	1.22	1.61	2.22	1.95	1.56
kW	1.58	1.48	1.64	1.59	0.93	0.51	0.58	0.61	0.94	1.24	1.71	1.50	1.20
Daily (kWh/day)	37.9	35.6	39.4	38.3	22.3	12.2	13.9	14.7	22.5	29.8	41.1	36.1	28.8
Monthly(kWh/Mo)	1,173	997	1,220	1,148	691	366	432	457	674	923	1,232	1,118	10,512

Air density (Baragoi): 1.05

Air density (std.): 1.226

Air density ratio: 86%

Safety margin:　10%

Annual Energy Output = 10,512 (kWh)

$$\text{Annual Capacity Factor (\%)} = \frac{\text{Annual Energy Output (kWh)}}{\text{Rated Power Output (kW)} \times 8760(\text{hr.})} = \frac{10{,}512}{7.5 \times 8760} = 16.0\%$$

$$\text{Actual Annual Energy Penetration} = \frac{2 \times 10{,}512}{182{,}500} \times 100(\%) = 11.2\%$$

3.3 Benefit from Wind

The cost of installation of wind turbine is simply the cost of the wind turbine, tower, wiring installation, taxes, and so on. Maintenance costs are expenses for servicing or repairing the wind system. Many experiences from commercial wind turbines in the U.S.A indicate that the cost of operating and maintaining small and medium size turbines is about 1 percent per kilowatt-hour.

One of the advantages using wind energy over generating electricity by conventional means is the free fuel. Once wind turbines are installed, the energy produced costs little for the remaining life of wind turbines. The table below shows the benefit from an installation of wind turbine with 15 kW. In Baragoi, the capacity of diesel generator is too large for the current power demands therefore fuel consumption rate is not good. The benefit is the diesel cost which was replaced by power supplied from the wind turbine.

Table 4　Benefit from Wind Turbine Installation

Generation capacity of the wind turbine	15	kW
Plant factor (Wind)	16.0%	
Operation hour per day	24	Hours
Operation day per year	360	days
Annual power generation (Wind)	20,736	kWh/Y
Life time of the wind turbine	20	Years
OM cost of the generation system (% of the investment)	2.0%	
Diesel fuel cost per litter	105.0	kSh/litter
Fuel consumption	0.67	litter/kWh
Fuel cost per kWh	70.35	kSh/kWh

Benefit (Replaced Diesel Cost)　　1,458,778 kSh/Y

4.0 Conclusions

On the basis of the wind monitoring data at Baragoi by MoE&P, the energy outputs from wind turbines were estimated. On the other hand, operation data of Baragoi diesel station was not enough because the data was not digitalised. Also, the installed capacity of diesel generator at Baragoi Diesel Power Station is not appropriate for the power demand of the covered area, therefore fuel consumption rate is high. Low penetration wind and diesel hybrid system is recommended in view of avoiding installing expensive electrical equipment or energy storage system such as battery or flywheel.

For the wind project, the most important pre-condition is to select a sufficiently windy place, and the capacity factor needs to be at least over 20%. The benefits from wind will be improved by selecting a site with higher wind potential.

5.0 Acknowledgements

We would like to express our deepest appreciation to all those who provided us the opportunities to complete this study, special gratitude to Rural Electrification Authority (REA) management and Japan International Corporation Agency (JICA).

We would also like to show gratitude to JICA Expert Team (JET), special mention to **Dr. Tsutomu Dei**. His passion for wind technology and readiness to share information has been immense. His enthusiasm for the topic has made a strong impression on us and we have and will always carry positive memories of our sessions.

Lastly, we would like to make a special mention to the Ministry of Energy and Petroleum (MOE&P) who shared with us the data for Baragoi, upon which this study is based. Further, we also thank the Kenya Power staff in Baragoi for sharing the information on operations of the existing diesel generators.

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Simple Pre-Feasibility Study
on
Wind Power Development in Baragoi

Rural Electrification Authority
Hannington Gochi

INTRODUCTION

1.1 Purpose of Simple Pre-F/S

A. Wind - diesel power plants can be used for power supply in autonomous systems where a connection to the national grid is either impossible or too expensive due to long transmission line.

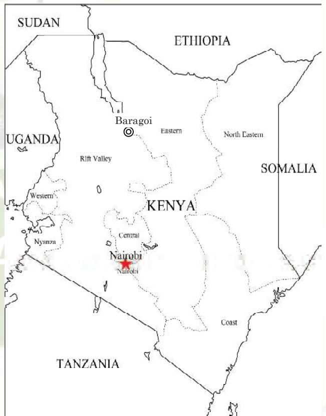
B. The most important purpose of a Wind -Diesel Hybrid system is to reduce the consumption of diesel fuel. In general, isolated diesel power stations are located in remote areas, and transportation and oil storage costs can therefore be reduced.

1.2 Location and Topography

Location:

Samburu County is located in Rift Valley.

Baragoi is located around 100 km from Maralal, in Samburu County.



Baragoi Diesel Power Station

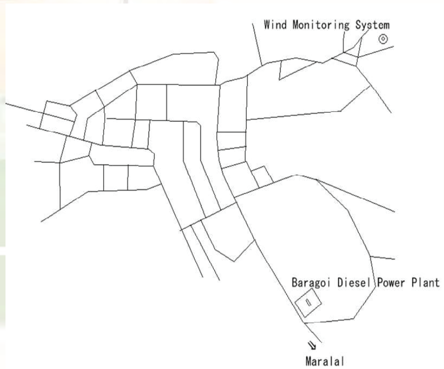
Location:

N 1.46’44’’,

E 36.47’26’’

Altitude:

1280 meters above sea level.



(Diesel Generator)

(Transformer)

(Control Unit)

(Fuel Tank)

1.3 Climate

Semi-arid

Temperature:

Averaging between 25°C during the coldest months (June and July) and 33°C during the hottest months (January to March).

Rainfall:

Total annual precipitation averages 700mm. April and November being the wettest months while the driest months are between July and September.

2.1 Socio - Economic Conditions

<u>Samburu North Sub-County</u>

Population: 59,801 (2009 census)

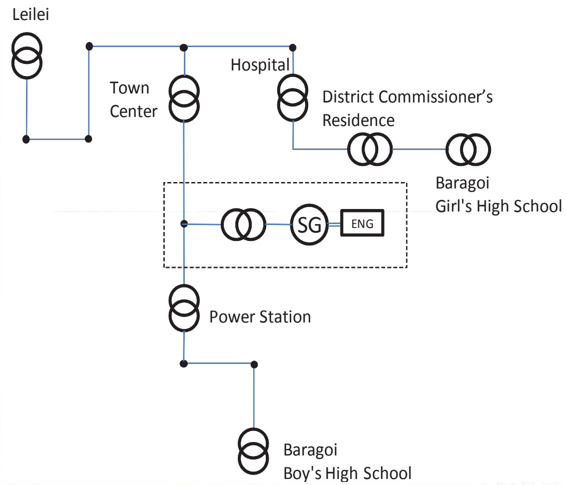
Households: 11,699 (2009 census)

<u>Baragoi town</u>

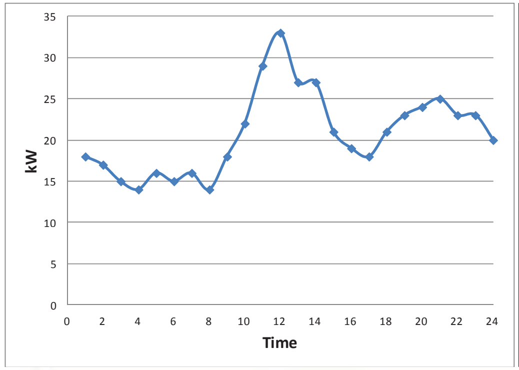
Population: 4,694 (2009 census)

Households: 924 (2009 census)

2.2 Power Demand



Power Demand of Baragoi Diesel Power Station



Time	kW
1	18
2	17
3	15
4	14
5	16
6	15
7	16
8	14
9	18
10	22
11	29
12	33
13	27
14	27
15	21
16	19
17	18
18	21
19	23
20	24
21	25
22	23
23	23
24	20

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3 WIND ANALYSIS

3.1 Wind Monitoring

Monitoring Height: 20m, 40m
Anemometer, Wind vane

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Monthly Average Wind Speed

Year	Month	average wind speed (m/s)		max. wind speed (m/s)	
		20m a.g.l.	40m a.g.l.	20m a.g.l.	40m a.g.l.
2010	Sep	4.4	5.1	14.2	14.8
	Oct	4.7	5.6	15.9	17.3
	Nov	3.4	5.1	16.7	17.6
	Dec	5.1	6.0	17.3	20.6
2011	Jan	5.3	6.1	17.4	17.8
	Feb	5.0	5.8	17.2	18.7
	Mar	5.1	6.1	20.1	22.0
	Apr	5.0	6.1	26.2	26.4
	May	4.0	5.0	18.1	20.0
	Jun	3.6	4.2	12.8	14.3
	Jul	3.8	4.4	13.6	14.2
	Aug	3.8	4.4	13.5	15.2
Average		4.4	5.3	16.9	18.2

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Table 2 Wind Speed Frequency

Wind Class	Range of Wind Speed (m/s)	No. of Data (40m a.g.l)	Frequency (40m a.g.l.)	No. of Data (20m a.g.l)	Frequency (20m a.g.l.)
0	0<V<0.5	37	0.1%	46	0.1%
1	0.5<=V<1.5	641	1.3%	233	0.5%
2	1.5<=V<2.5	1997	4.2%	4352	9.1%
3	2.5<=V<3.5	4376	9.2%	8133	17.1%
4	3.5<=V<4.5	7821	16.4%	11242	23.6%
5	4.5<=V<5.5	10146	21.3%	9448	19.9%
6	5.5<=V<6.5	8682	18.2%	6614	13.9%
7	6.5<=V<7.5	6315	13.3%	4287	9.0%
8	7.5<=V<8.5	4304	9.0%	2172	4.6%
9	8.5<=V<9.5	2114	4.4%	812	1.7%
10	9.5<=V<10.5	801	1.7%	204	0.4%
11	10.5<=V<11.5	251	0.5%	35	0.1%
12	11.5<=V<12.5	85	0.2%	7	0.0%
13	12.5<=V<13.5	10	0.0%	3	0.0%
14	13.5<=V<14.5	3	0.0%	0	0.0%
15	14.5<=V<15.5	2	0.0%	0	0.0%
16	15.5<=V<16.5	3	0.0%	0	0.0%
17	16.5<=V<17.5	0	0.0%	0	0.0%
18	17.5<=V<18.5	0	0.0%	0	0.0%
19	18.5<=V<19.5	0	0.0%	0	0.0%
20	19.5<=V<20.5	0	0.0%	0	0.0%
		47588	100%	47588	100%

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Over 15% of wind speed frequency was recorded between 4m/s and 6m/s. Around 69% of wind speeds were recorded at 4.5 m/s and higher.

Wind Speed Frequency

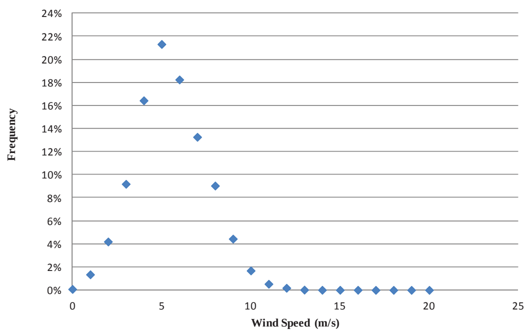

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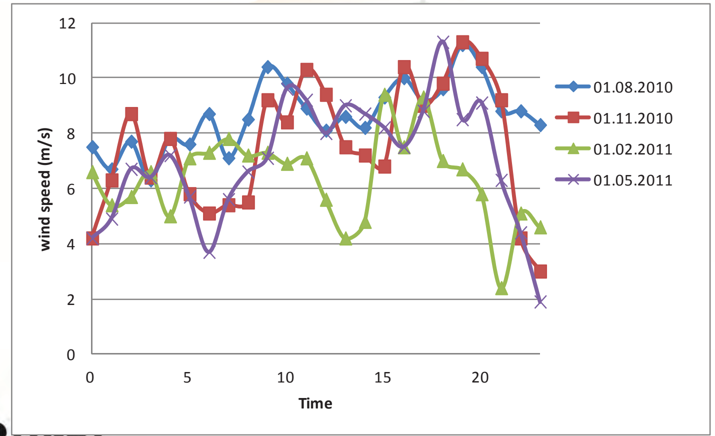
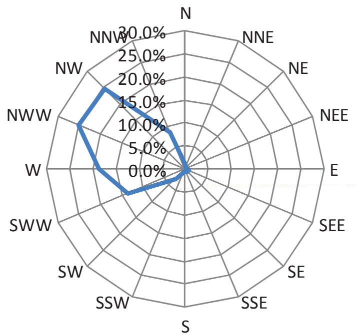
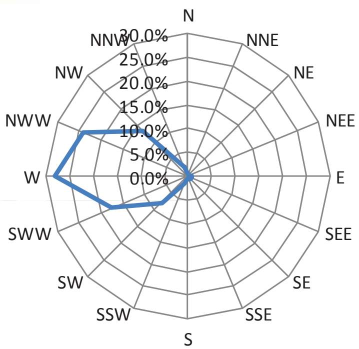
Figure .6 Wind Speed Frequency

Diurnal Wind Speed



Wind Direction

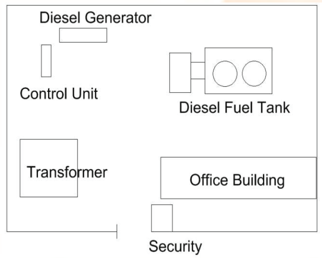




Wind axis is defined as the direction of the prevailing wind and the two immediate directions on both sides, and the symmetric directions of these three directions. In total, 6 of the 16 azimuth angles are designated as the wind axis. In the case of Baragoi, more than 70% of wind direction is in the wind axis.

4 PRELIMINARY DESIGN AND COST ESTIMATE

4.1 Baragoi Diesel Power Station



(Diesel Generator)

(Transformer)

(Control Unit)

(Fuel Tank)

4.2 Proposed Wind-Diesel Hybrid System

Table 3 Estimation of Energy Output from Wind

Wind Speed Bin (m/s)	Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.3	0.03	0.03	0.03	0.03	0.05	0.07	0.06	0.06	0.05	0.04	0.02	0.03	0.04
5	0.8	0.16	0.13	0.13	0.14	0.18	0.20	0.21	0.21	0.23	0.18	0.15	0.15	0.17
6	1.7	0.32	0.27	0.27	0.34	0.32	0.21	0.27	0.25	0.31	0.35	0.38	0.33	0.30
7	2.6	0.43	0.41	0.43	0.45	0.33	0.12	0.14	0.18	0.25	0.35	0.51	0.44	0.34
8	3.7	0.46	0.44	0.53	0.47	0.23	0.05	0.07	0.08	0.23	0.34	0.60	0.43	0.33
9	4.9	0.34	0.27	0.47	0.37	0.09	0.01	0.00	0.02	0.12	0.23	0.33	0.29	0.22
10	6.2	0.19	0.23	0.19	0.19	0.01	0.00	0.00	0.00	0.02	0.10	0.15	0.14	0.10
11	7.5	0.07	0.10	0.06	0.07	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.04
12	8.0	0.04	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.01
13	8.0	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	7.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	2.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		2.05	1.92	2.13	2.07	1.21	0.66	0.75	0.80	1.22	1.61	2.22	1.95	1.56

Power (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Net kW	2.05	1.92	2.13	2.07	1.21	0.66	0.75	0.80	1.22	1.61	2.22	1.95	1.56
kW	1.58	1.48	1.64	1.59	0.93	0.51	0.58	0.61	0.94	1.24	1.71	1.50	1.20
Daily (kWh/day)	37.9	35.6	39.4	38.3	22.3	12.2	13.9	14.7	22.5	29.8	41.1	36.1	28.8
Monthly(kWh/Mo)	1,173	997	1,220	1,148	691	366	432	457	674	923	1,232	1,118	10,512

Air density (monitored)	1.05
Air density (std.)	1.226
Air density Ratio	86%
Safety Margin	10%

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Capacity Factor = 1.2 / 7.5 = 16.0%

4.3 Selection of Wind Turbine

- Penetration ratio can be designed to be less than 15% by installing two wind turbines of 7.5 kW.
- Annual Energy Penetration = 10,512 × 2 / 182,500

= 11.52 %

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Benefit from wind turbine installation

Generation capacity of the wind turbine	15	kW
Capacity factor (Wind)	16.0%	
Operation hour per day	24	Hours
Operation day per year	360	days
Annual power generation (Wind)	20,736	kWh/Y
Life time of the wind turbine	20	Years
OM cost of the generation system (% of the investment)	2.0%	
Diesel fuel cost per litter	105.0	kSh/litter
Fuel consumption	0.67	litter/kWh
Fuel cost per kWh	70.35	kSh/kWh

Benefit (Replaced Diesel Cost) 1,458,778 kSh/Y

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Capacity Factor vs. EIRR

Baragoi Pre-F/S:
Capacity Factor: 16%, EIRR = 10.0%

Capacity Factor	EIRR
15%	8.8%
20%	14.5%
25%	19.6%

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Consideration

- For a wind project, most important pre-condition is to select a sufficiently windy place.
- Capacity factor needs to be at least over 20%. The benefits from wind will be improved by selecting a site with higher wind potential.
- Optimization of Installed capacity of diesel generator at Baragoi Diesel Power Station should be considered as it is not appropriate for the current power demand

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Thank You

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